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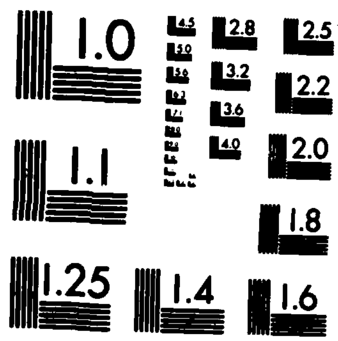

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AIDS TO NAVIGATION TURN LIGHTS PRINCIPAL FINDINGS: EFFECTS OF TURN LIGHTING CHARACTERISTICS, BUOY ARRANGEMENTS, AND SHIP SIZE ON NIGHTTIME PILOTING

Eclectech Associates
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February 1983

Interim Report

Prepared for

U.S. Coast Guard
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16. Abstract

This experiment is one in a series of simulator experiments contributing to the United States Coast Guard's Performance of Aids to Navigation Systems Program, meant to provide quantitative data on piloting performances in narrow channels with turns. This experiment investigates the effects of buoy lighting characteristics in the turn on nighttime piloting. The following variables were evaluated: flash rate (quick, 2.5 sec, 4 sec); random versus synchronized flash; number and arrangement of turn buoys; and ship size (30,000 versus 80,000 dwt). Other experiments in the series provided daytime conditions for comparison.

Day/night differences were found in the use of strategies to maneuver through the turn, with the daytime track more gradual. Of the flash rates, quick flash supported performance most like daytime. The need for quick flash is most critical at the turn point, or inside apex buoy. Synchrony of turn buoys did not meaningfully contribute to performance. A three-buoy turn arrangement supported better turn performance than a two-buoy arrangement, a difference that was more critical for the larger ship size.

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METRIC CONVERSION FACTORS

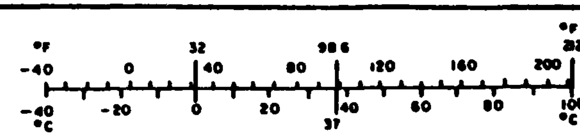
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in ≡ 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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EXECUTIVE SUMMARY

INTRODUCTION

The experiment reported here contributes to the United States Coast Guard's Performance of Aids to Navigation Systems Program, which is meant to establish system design guidelines for U.S. ports. It is one in a series of experiments done on a simulator developed for the project at Eclectech Associates, Inc. in North Stonington, Connecticut. Earlier work on the project is summarized in a report entitled "Draft SRA/RA Design Manual for Restricted Waterways." The final product of the program will be a revision of this manual, incorporating new findings, including those of the present experiment.

The primary purpose of this experiment is an evaluation of turn lighting characteristics and their effects on piloting performance. For this reason, the conditions are limited to visual piloting at night with only buoys as aids. A secondary, and related purpose, is the evaluation of the effect of number of buoys marking the turn for nighttime piloting. The variables considered are the following:

Flash rate (quick, 2.5 sec, 4 sec)

Random versus synchronized flash

Number of turn buoys (two versus three)

Ship size (30,000 versus 80,000 dwt)

Not all combinations of these conditions were run: instead, a minimum number of the possibilities were selected to result in the most generalizable findings. The findings are summarized in the following short sections.

DAY/NIGHT DIFFERENCES

Nighttime scenarios in the present experiment are comparable to daytime scenarios in earlier experiments. The following observations can be made:

- There appear to be different strategies for exiting the turn in the daytime and at night. Daytime performance shows the distribution of ship transits exiting to the outside of the turn with a small spread. Nighttime performance shows the distribution of transits exiting the turn close to the centerline with a larger spread.

- The day/night difference in strategy appears in both two- and three-buoy turn arrangements.

- Apparently, pilots compensate for a nighttime uncertainty as to where the outside edge of the channel is by trying harder to avoid it. A consideration of both the placement and spread of the distribution of tracks shows that nighttime performance results in a higher risk, despite their efforts.

- Those nighttime scenarios that have three quick-flash buoys marking the turn show performance most like the daytime performance. Slower flash rates in the turn show performance more unlike daytime performance.

- Nighttime piloting performance is more difficult and less safe than daytime piloting performance. Turn light characteristics may moderate the difference.

TURN LIGHTING CHARACTERISTICS

A variety of turn lighting characteristics were evaluated. The following observations can be made:

- Buoy lighting characteristics assist piloting in two ways. Appropriate flash rates provide quantitative information for maneuvering through the turn and synchronization facilitates the identification of straight channel segments and entrances to restricted waters against a cluttered background of lights.

- Turn buoys lighted with quick flash (0.3 seconds on, 0.7 seconds off) support better piloting performance than slower rates. Flash rates of 2.5 seconds (0.3 seconds on, 2.2 seconds off), and 4 seconds (0.4 seconds on, 3.6 seconds off) are not meaningfully different.

- Observed differences among conditions strongly support the recommendation that the turnpoint or inside apex buoy of a turn be lighted with quick flash. It is less critical that other buoys in the turn have this characteristic. Under less demanding turn conditions, other buoys can be lighted by slower flash rates. (Earlier experiments identified "less demanding turn conditions" as those involving lower-angle turns, smaller ships, and wider channels.)

- Synchronizing three lights with 2.5-second flash has a positive effect on piloting performance only in the approach to the turn, where its contribution is not needed. Synchronizing three lights with 4-second flash has a negative effect on performance, possibly because of the relatively long interval when the pilot sees nothing marking the turn.

- While synchronized lighting may have other functions in the design of aids to navigation, it does not seem to be advantageous in marking the turn.

- Quick-flash turn arrangements result in better piloting performance than synchronized arrangements. And the pilots preferred quick flash.

- If a turn is to be improved by investment in lighting characteristics, quick flash is preferable to synchrony.

ARRANGEMENT OF BUOYS IN THE TURN

Evaluation of variables identified in earlier conditions as having major effects on performance in noncutoff turns was continued in the present experiment. The variables considered over several experiments including day/night, ship size (30,000 versus 80,000 dwt), and arrangement of buoys in the turn. The arrangements considered were the following:

- one buoy at the inside apex of the turn
- two buoys, at the inside and outside apexes of the turn
- three buoys, at the inside apex and above and below the outside apex

Observed performance supports the following generalities:

- Ship size is a variable of maximum effect. For the [illegible],000 dwt ship, or for ships much above the 30,000 dwt ship in size [illegible] the maximum arrangement of three buoys in the turn should be considered.
- For ships close to the 30,000 dwt ship in size, fewer buoys in the turn are feasible. As few as one turn buoy may be considered if other conditions are favorable.
- Observed differences between daytime and nighttime performance in the turns suggest operational recommendations. For larger ships on sparsely marked turns, it may be worthwhile to wait for daylight.

ARRANGEMENTS OF BUOYS IN THE TURN AND TURN LIGHTING CHARACTERISTICS

- The recommendations for number of buoys and for lighting characteristics are not independent. For those conditions where additional buoys are strongly recommended, quick flash should be used. For those situations where additional buoys are less important, the quick-flash lights are less important.
- For larger ships, the turn should be marked with three quick-flash buoys for nighttime transits. Smaller ships present favorable condition for which options are more varied: fewer buoys and slower flash rates for buoys other than the inside apex may be considered.

FACTORS NOT CONSIDERED IN THIS REPORT

An exhaustive treatment of those conditions that lessen dependence on turn marking and permit less than the maximum marking is beyond the scope of this report. Earlier experiments have evaluated lower angle turns (e.g., 15 degrees rather than 35), wider channels (e.g., 800 feet rather than 500), widening of the turn by dredging, a well-marked straight segment beyond, and ranges beyond as possibilities. These are discussed in the draft SRA/RA manual of 1982 and will be reconsidered in the planned final version of that manual.

SECTION 1

INTRODUCTION

1.1 OVERVIEW OF THE AIDS TO NAVIGATION PROJECT

As part of its function to promote safety in U.S. harbors and channels, the United States Coast Guard is responsible for the design, care, and maintenance of aids to navigation. The Coast Guard is sponsoring a simulator-based research program to evaluate the effectiveness of aids to navigation systems as a part of this responsibility. The aids to navigation systems of interest to the Coast Guard include: visual aids, radar aids, and radio aids. The objective of the project is to develop design criteria for the placement of visual aids for use alone and in conjunction with radar and radio aids in restricted waterways. This systematic approach is intended to enable the Coast Guard to identify weaknesses in existing aids to navigation systems, to design new systems, and to evaluate the relative potential for accidents under the conditions studied.

The current investigation is part of the program to evaluate the effects of visual aids to navigation on piloting performance. The ability to navigate safely through a narrow channel is the result of a complex set of processes, under the control of a variety of variables. A study by Bertsche and Cook documented the large group of variables expected to affect visual piloting and from which a subset of variables of interest was chosen for evaluation in simulator-based experiments.[1] In recognition of this complexity, this project has been divided into a series of self-contained experiments that focus on only a small, manageable number of variables that may interact with each other. This modular design permits the systematic and efficient investigation of the piloting process in a way that maximizes real-world conditions while maintaining a high degree of control over the variables of interest. Table 1 lists the 15 variables of interest for this project and the experiments in which they were examined.

Complementing the study by Bertsche and Cook, another study by Bertsche and Mercer identified the characteristics of channel design and aids to navigation found in 32 major U.S. ports.[2] From these two studies, the 15 variables listed in Table 1 were selected for detailed investigation on the basis that they would generate inferences which have the broadest possible real-world applications.

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[1] W.R. Bertsche and R.C. Cook. "Analysis of Visual Navigational Variables and Interactions." U.S. Coast Guard, Washington, D.C., October 1979.

[2] W.R. Bertsche and R.T. Mercer. "Aids to Navigation Configurations and the Physical Characteristics of Waterways in 32 Major U.S. Ports." U.S. Coast Guard, Washington, D.C., October 1979.

TABLE 1. NAVIGATION PROCESS VARIABLES

VARIABLE	EXPERIMENT WHICH EVALUATED THE VARIABLE
Ship	
Perspective view	Ship Variables
Speed	Ship Variables
Maneuverability/size	Ship Variables, Turn Lighting
Channel dimensions	
Banks	None
Width	Channel Width
Turn angle	CAORF, Range Light
Turn radius (configuration)	CAORF
Environmental factors	
Current/wind	CAORF, Channel Width, Ship Variables, One Side, Range Light
Day/night	CAORF, Turn Lighting
Visibility/detection distance	CAORF, One Side
Traffic ships	CAORF
AN placement	
Spacing	CAORF, Channel Width, Ship Variables, One Side
Straight channel marking	CAORF, Channel Width, Ship Variables, One Side
Flash period	Turn Lighting
Turnmarking	CAORF, Ship Variables, One Side, Turn Lighting

The first simulator-based experiment on floating visual aids to navigation was conducted at the Maritime Administration's Computer Aided Operation Research Facility (CAORF) in New York.[3] All subsequent experiments for the project were conducted at the bridge simulator built for the U.S. Coast Guard project by Eclectech Associates in North Stonington, Connecticut. Both bridge simulators are equipped with a full complement of bridge equipment and provide the ship hydrodynamics, environmental effects, and visual scene required for these experiments. A comparison of differences and similarities in pilot performance between the two simulators is discussed in detail in the Channel Width and Ship Variables experiments.[4,5]

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[3]M.W. Smith and W.R. Bertsche. "Aids to Navigation Report on the CAORF Experiment. The Performance of Visual Aids to Navigation as Evaluated by Simulation." U.S. Coast Guard, Washington, D.C., August 1980.

[4]M.W. Smith and W.R. Bertsche. "Aids to Navigation Principal Findings Report on the Channel Width Experiment: The Effects of Channel Width and Related Variables on Piloting Performance." U.S. Coast Guard, Washington, D.C., January 1981.

[5]W.R. Bertsche, D.A. Atkins, and M.W. Smith. "Aids to Navigation Principal Findings Report on the Ship Variables Experiment: The Effect of Ship Characteristics and Related Variables on Piloting Performance." U.S. Coast Guard, Washington, D.C., April 1981.

This series of experiments varied the conditions that regulate or control the amount of visual information that visual aids provide the pilot:

1. The CAORF experiment tested a variety of environmental conditions, channel dimensions, and aids to navigation for their effects on piloting performance.[6]

2. The Channel Width experiment assessed the effects of channel width, wind and current, and aids to navigation placement on piloting performance.[7]

3. The Ship Variables experiment evaluated the effects of three ship related variables and aids to navigation on piloting performance.[8]

4. The One-Side Channel Marking experiment measured the effects of visibility, buoy spacing, and buoy configuration on piloting performance.[9]

5. The Range Light experiment examined the effects of range lights as the only aid to navigation on piloting performance.[10]

In addition to each experiment's evaluation as a separate component in the Aids to Navigation project, the conclusions from these separate experiments have been integrated in the "Draft SRA/RA Manual for Restricted Waterways," in a form applicable to the design of navigation systems.[11]

1.2 PURPOSE OF THE TURN LIGHTING CHARACTERISTICS EXPERIMENT

The present experiment is part of the Phase II Addendum to extend the domain of the Draft SRA/RA Manual for Restricted Waterways. The primary purpose of this experiment is to assess the effects of different lighting characteristics of turn buoys on piloting performance. A second purpose is to assess the effects of different buoy arrangements and ship size under nighttime piloting conditions. To complete these objectives, the following variables were considered:

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[6]M.W. Smith and W.R. Bertsche, op. cit., October 1979.

[7]M.W. Smith and W.R. Bertsche, op. cit., August 1980.

[8]W.R. Bertsche, D.A. Atkins, and M.W. Smith, op. cit., January 1981.

[9]K.L. Marino, M.W. Smith, and W.R. Bertsche. "Aiods to Navigation Principal Findings Report: The Effect of One-Side Channel Marking and Related Conditions on Piloting Performance." U.S. Coast Guard, Washington, D.C., July 1981.

[10]Ibid.

[11]W.R. Bertsche, M.W. Smith, K.L. Marino, and R.B. Cooper. "Draft SRA/RA Systems Manual for Restricted Waterways." U.S. Coast Guard, Washington, D.C., February 1982.

- Flash rate (quick, 2.5 seconds, 4 seconds)
- Random versus synchronized flash
- Number of turn buoys (two versus three)
- Ship size (30,000 versus 80,000 dwt)

There are a total of 48 possible conditions that could be run for this experiment. However, running all possible combinations would be both inefficient and impractical. Some of these conditions would not address relevant questions and it would take an excessive amount of time to run all 48 conditions. Instead, a selected group of conditions were selected based upon the variables listed and some of the interactions relevant to the overall objectives of the Aids to Navigation project.

1.3 EXPERIMENTAL CONDITIONS

Table 2 lists the experimental conditions and Table 3 lists the specific comparison of conditions made. One of the conditions (Scenario 7) was dropped from the experiment when the presimulation pilot reported that the synchronized flash rate of Scenario 7 was not noticeably different from the unsynchronized flash rate of Scenario 4. A diagram of each scenario is found in Appendix A.

1.4 VARIABLES AFFECTING NIGHTTIME JUDGMENTS

The piloting process is mediated by the *quantity and quality* of visual information available to the pilot for making decisions or perceptual judgments about the navigation process. Under nighttime conditions, the characteristics of point light sources as the sole form of visual informa-

TABLE 2. EXPERIMENTAL CONDITIONS

Scenario	Number of Buoys	Flash Rate	Synchronization	Ship Size (1,000 dwt)
1	Three	Quick	Random	30
2	Three	2.5 sec	Random	30
3	Three	4 sec	Random	30
4	Three	Varied	Random	30
5	Three	2.5 sec	Synchron	30
6	Three	4 sec	Synchron	30
7	Three	Varied	Synchron	30
8*	Two	Quick	Random	30
9	Two	2.5 sec	Synchron	30
10*	Two	Quick	Random	80

*These scenarios must be run first and have a longer running time than the others.

tion, play an important role in influencing piloting behavior. Flash rate is believed to affect the amount of infomation available and consequently piloting performance in three ways. It affects:

1. detection of light sources that represent the buoys

2. identification of what the point light sources represent

3. quantification of the information that establishes where ownship is in relation to the point light source

For a more detailed discussion of how manipulation of visual information through changes in lighting characteristics of the turn buoys may influence piloting decisions and piloting performance, refer to Appendix B.

The following discussion explains the potential effects of variables that may influence a pilot's perceptual judgments. It justifies the selection of the scenarios summarized in Table 2. All scenarios represent conditions used or considered by the Coast Guard in marking turns in narrow channels.

1.4.1 Flash Rate

There is a tradeoff between maintenance costs and perceptual judgments with changes in flash rate. As flash rate decreases, so do the maintenance costs, while the perceptual tasks of detection, identification, and quantification take more time and are more prone to error. The question is: does a decrease in flash rate translate into significantly poorer piloting performance in narrow channels? Scenarios 1, 2, and 3 (see Table 3) address this question. All three scenarios consist of a three-buoy noncutoff turn that differ only in flash rate. The three buoys in the turn all flash at the same rate in random temporal relationship to each other. Scenario 1 is lighted with a quick-flash rate (0.3 seconds on, 0.7 seconds off). Scenario 2 is lighted with a 2.5-second flash rate (0.3 seconds on, 2.2 seconds off). Scenario 3 is lighted with a 4-second flash rate (0.4 seconds on, 3.6 seconds off).

1.4.2 Quick Flash

The effects of quick flash occupy a category within the variable flash rate that merits special attention, apart from comparison with other flash rates. Results from the CAORF experiment indicate that performance in the turn under nighttime conditions with three quick-flash buoys was not significantly different from performance under daytime conditions. Subjective evaluation of turns with quick flash by shiphandlers is in agreement with this empirical finding. A practical question to ask is: is there any meaningful performance decrement with fewer than three quick-flash buoys in the turn? Is it possible to reduce the number of quick-flash buoys in the turn without any significant loss in piloting performance? Scenarios 1 and 4 were used to compare differences in performance for a number of quickflash buoys.

TABLE 3. PERFORMANCE COMPARISONS EVALUATION

BUOY ARRANGEMENT

1 ARRANGEMENT OF BUOYS IN THE TURN (QUICK FLASH)

——— THREE BUOYS (SCENARIO 1)
- - - - TWO BUOYS (SCENARIO 8)

2 ARRANGEMENT OF BUOYS IN THE TURN (POOLED)

——— THREE BUOYS (SCENARIO 1–6)
- - - TWO BUOYS (SCENARIO 8,9)

SHIP SIZE

3 SHIP SIZE (TWO–BUOY TURN)

——— 30,000 DWT SHIP (SCENARIO 8)
- - - - 80,000 DWT SHIP (SCENARIO 1[illegible]

FLASH RATE

4 FLASH RATE FOR THE THREE–BUOY TURN

——— QUICK FLASH (SCENARIO 1)
- - - - 2.5 SEC. FLASH (SCENARIO 2)

5 FLASH RATE FOR THE THREE–BUOY TURN

——— 4 SEC. FLASH (SCENARIO 3)
- - - - 2.5 SEC. FLASH (SCENARIO 2)

6 FLASH RATE FOR THE THREE–BUOY TURN (POOLED)

——— 4 SEC FLASH (SCENARIO 3,6)
- - - - 2.5 SEC. FLASH (SCENARIO 2,5)

FLASH RATE (CONTINUED)

7 NUMBER OF QUICK FLASH IN THREE–BUOY TURN

——— THREE QUICK FLASH (SCENARIO 1)
- - - - TURN POINT ONLY (SCENARIO 4)

8 CHARACTERISTIC OF TURN POINT, THREE–BUOY TURN (POOLED)

QUICK FLASH (SCENARIO 1,4)
SLOWER FLASH (SCENARIO 2,3,5,6)

SYNCHRONY

9 SYNCHRONY, 2.5 SEC. FLASH

RANDOM (SCENARIO 2)
SYNCHRONIZED (SCENARIO 5)

10 SYNCHRONY, 4 SEC. FLASH

RANDOM (SCENARIO 3)
SYNCHRONIZED (SCENARIO 6)

11 QUICK FLASH VERSUS SYNCHRONY, TWO–BUOY TURN

QUICK FLASH (SCENARIO 8)
SYNCHRONIZED (SCENARIO 9)

12 QUICK FLASH VERSUS SYNCHRONY, THREE–BUOY TURN

QUICK FLASH (SCENARIO 1)
SYNCHRONIZED (SCENARIO 5)

1.4.3 Synchronization

The normally random temporal relationship of flashing lights to those around them has potentially negative implications for a pilot's perceptual judgments. The detection and identification of a buoy configuration are difficult against a cluttered background of lights and quantification techniques are limited. The pilot is limited to using only one light at a time or holding eclipsed lights in memory to compare them to their lighted neighbors. Synchronization of the turn lights has the potential to improve detection, identification, and quantification. The simultaneous presence of all buoy lights in the turn against a background of randomly flashing lights should facilitate all three perceptual tasks. Any improvement in quantification during the on phase of the flash cycle may be offset, however, by the off phase. During the time period when all the lights are off, no quantification would be possible and the slower the flash rate, the longer the pilot would lack information necessary to quantify the relationship between ownship's position and the buoy lights. Comparisons using Scenarios 5, 6, and 9 assess the effectiveness of the synchronization of slow flash rates in the turn and the extent to which it facilitates piloting decisions.

1.4.4 Two- Versus Three-Buoy Arrangements in the Turn

The number of buoys marking a turn influenced piloting performance in a number of experiments. The CAORF experiment demonstrated major differences in performance between one-buoy and three-buoy turns. There was an interaction between number of buoys and day/night differences such that nighttime performance with a one-buoy turn was especially poor (even with good straight channel marking beyond). While that experiment evaluated nighttime conditions, it did not evaluate two-buoy turns which are hypothesized to be similar to one-buoy turns. The One-Side Channel Marking experiment did compare three-buoy and two-buoy turns, but only under daytime conditions. That experiment demonstrated poorer performance for the two-buoy turn statistically, but this decrement was not practically meaningful. The possibility remained that nighttime conditions might magnify the disadvantage of the two-buoy turn as it did that of the one-buoy turn. The present experiment with its focus on nighttime turn marking, evaluates this possibility. This evaluation would have wide applicability since two-buoy noncutoff turns comprise 15 percent, a substantial number of cases in U.S. harbors.[12] The results will augment the SRA/RA design manual by the addition of performance data for the two-buoy turns under nighttime conditions.

Scenario 8, listed in Table 2 and illustrated below, is included to evaluate two-buoy turns under nighttime conditions. It has two buoys, one each at the inside and outside apex of the turn, presenting a gate to the pilot as the ship approaches the turn. The two buoys have quick-flash lights, making this scenario comparable to Scenario 1 with the three quick-flash turn lights. Performance with the one-buoy turn at night in the CAORF experiment suggests the ship's track will be further to the outside than under daytime conditions. This experiment demonstrates how far to the outside.

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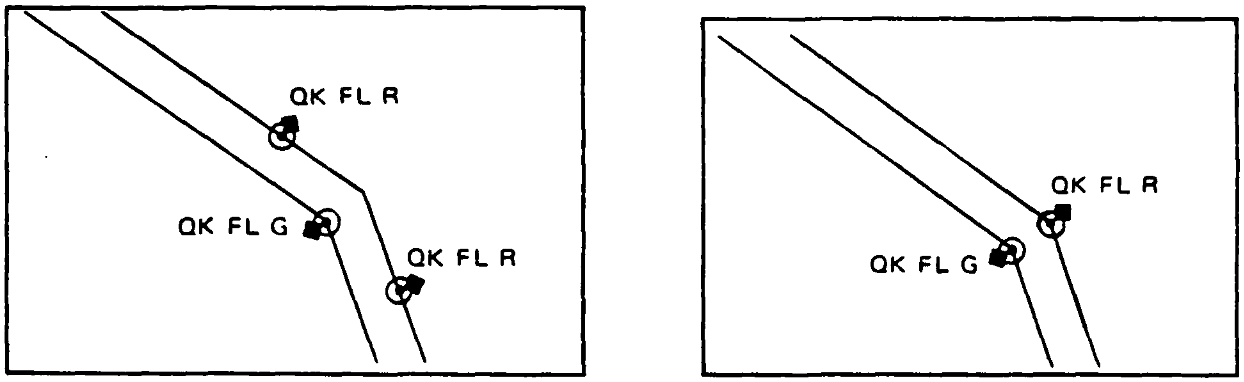
[12] W.R. Bertsche and R.T. Mercer, op. cit., October 1979.



SCENARIO 1 SCENARIO 8

1.4.5 Ship Size and Buoy Configuration

Previous Aids to Navigation experiments indicate that ship size interacts with number of turn buoys. In the Ship Variables experiment, both 30,000 dwt and 80,000 dwt ships were run with both one-buoy and three-buoy turns (in daylight conditions). It reported that, in general, piloting performance with the 80,000 dwt ship is more sensitive to differences in aid arrangement than with the smaller ships. The combination of large ship and one-buoy turn resulted in the poorest performance. With the larger ship, the pilots tended to start the turn too late and exit the turn to the outside, skimming the channel edge in some cases. Performance in the One-Side Channel Marking experiment with the 30,000 dwt ship and the two-buoy turn was similar, but less exaggerated. A two-buoy condition using an 80,000 dwt ship under nighttime conditions has not been evaluated yet and is included in this experiment as Scenario 10. Scenario 10 consists of a two-buoy turn with quick-flash lights and an 80,000 dwt ship. It is compared to Scenario 8 which differed only in ship size (30,000 dwt).

1.5 CONSTANT CONDITIONS

The constant conditions chosen here were similar to those used in two previous experiments: the One Side Channel Markings and the Ship Variables experiments. The similarity maximizes comparability between experiments. The selected conditions for Scenarios 1 through 7 and Scenario 9 are summarized in Table 4. Scenarios 8 and 10 are discussed in Section 1.7 that follows.

1. Channel dimensions. The constant scenario contains the same two channel segments that were used in the earlier experiments. The basic scenario for this experiment is illustrated in Figure 1. The segments were 2 and 2-1/2 nm long (the ship did not transit the whole channel), 500 feet wide, and 36 feet deep under the 35-foot draft of the 30,000 dwt ship. There were no bank effects. The two segments were connected by a 35-degree noncutoff turn that is the focus of the experiment.

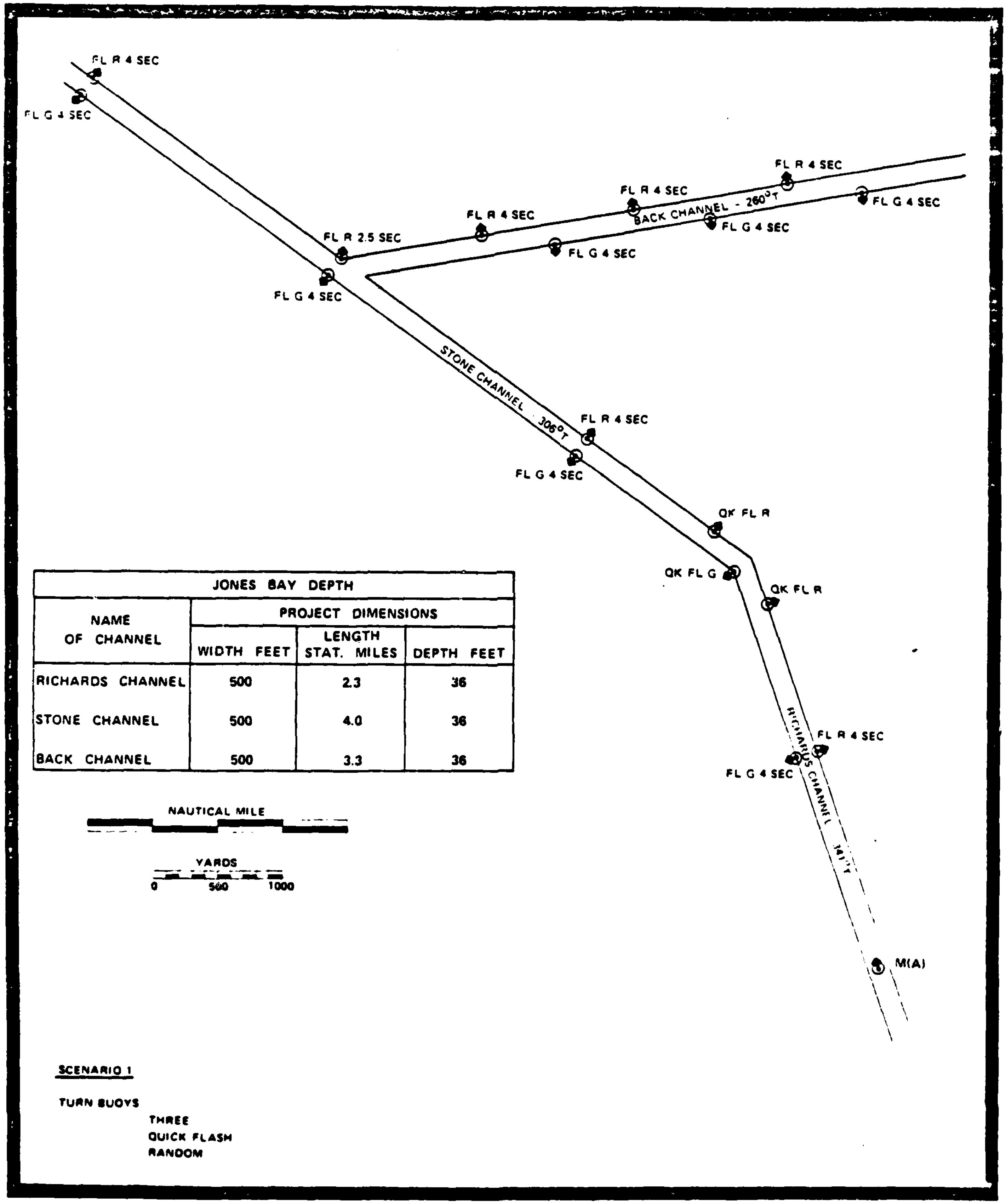
TABLE 4. CONSTANT CONDITIONS FOR SCENARIOS 1-7, 9

1. Channel dimensions:	• 500-foot width • 36-foot depth • 35-degree noncutoff turn • background channel present
2. Environmental effects:	• following wind and current changing to port quarter • nighttime • 3 nm visibility
3. Ship:	• 30,000 dwt tanker • split house, midship bridge • 45-foot height of eye • 6.6 knots
4. Bridge:	• helmsman • engine order telegraph • gyrocompass • chart
5. Visual scene:	• ship bow, bridge wings • red and green buoy lights against black background

The physical arrangement of the scenario differed from that of the earlier experiments by the addition of another channel crossing in the background as the ship moves up the channel. The relationship of the segments is illustrated in Figure 1. The purpose of this segment was the addition of background lighting to the pilot's view. He never reached or transited that channel.

2. Environmental conditions. The present experiment was run under the nighttime conditions in order to explore turn lighting effects. Visibility was 3 nm. This visibility allowed the pilot to see the lights of the background channel at initialization. The wind and current were the same as those in the earlier experiment. In the lower leg of the channel, there was a following wind averaging 30 knots and gusting (see Figures 2 and 3). The wind maintained its average direction and speed throughout the scenario and was on the port quarter at the turn. The current changed from following in the first segment to the port quarter after the turn. It changed in speed as well as direction. For most of the scenarios, it was following at 1.2 knots at initialization. It decreased so that it was 3/4 knot on the port quarter as the ship exited the turn (the crosstrack component is 1/4 knots), and continued to decrease as long as the scenario continued.

3. Ship characteristics. For most of the scenarios, the ship used was the 30,000 dwt tanker used in the earlier experiments. It is 595 feet long, 84 feet in beam, and has a 35-foot draft (in a 36-foot channel to make it relatively difficult to handle for its size). It has a split house with a midship bridge that puts the eyepoint 223 feet back from the bow, 75 feet ahead of the center of gravity, and 45 feet above the water. The information on this ship, given to the pilots, appears as Figure 4.



JONES BAY DEPTH			
NAME OF CHANNEL	PROJECT DIMENSIONS		
	WIDTH FEET	LENGTH STAT. MILES	DEPTH FEET
RICHARDS CHANNEL	500	2.3	36
STONE CHANNEL	500	4.0	36
BACK CHANNEL	500	3.3	36

Figure 1. Basic Scenario Design

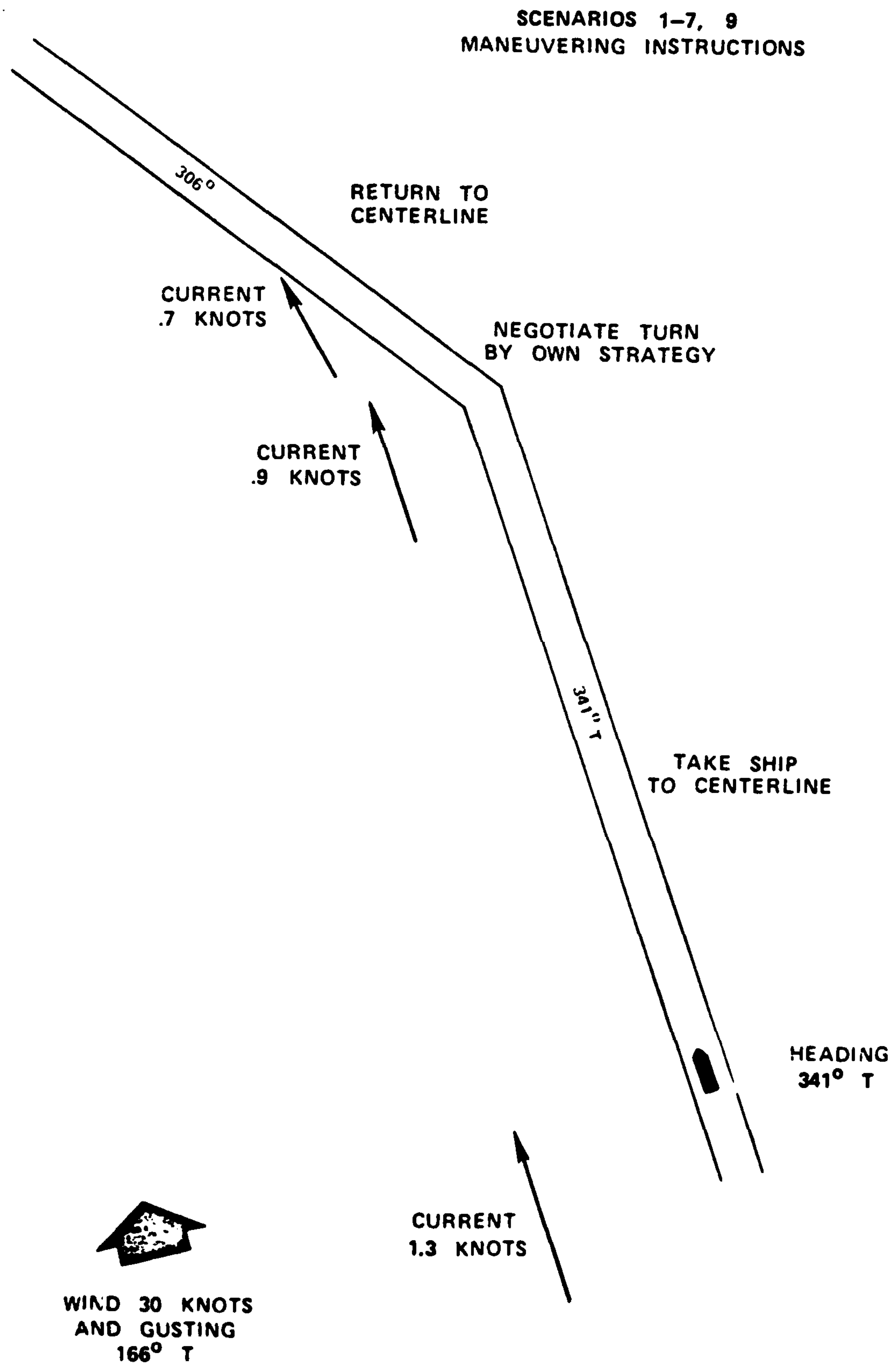


Figure 2. Performance Requirements for Scenarics 1 through 6, 9

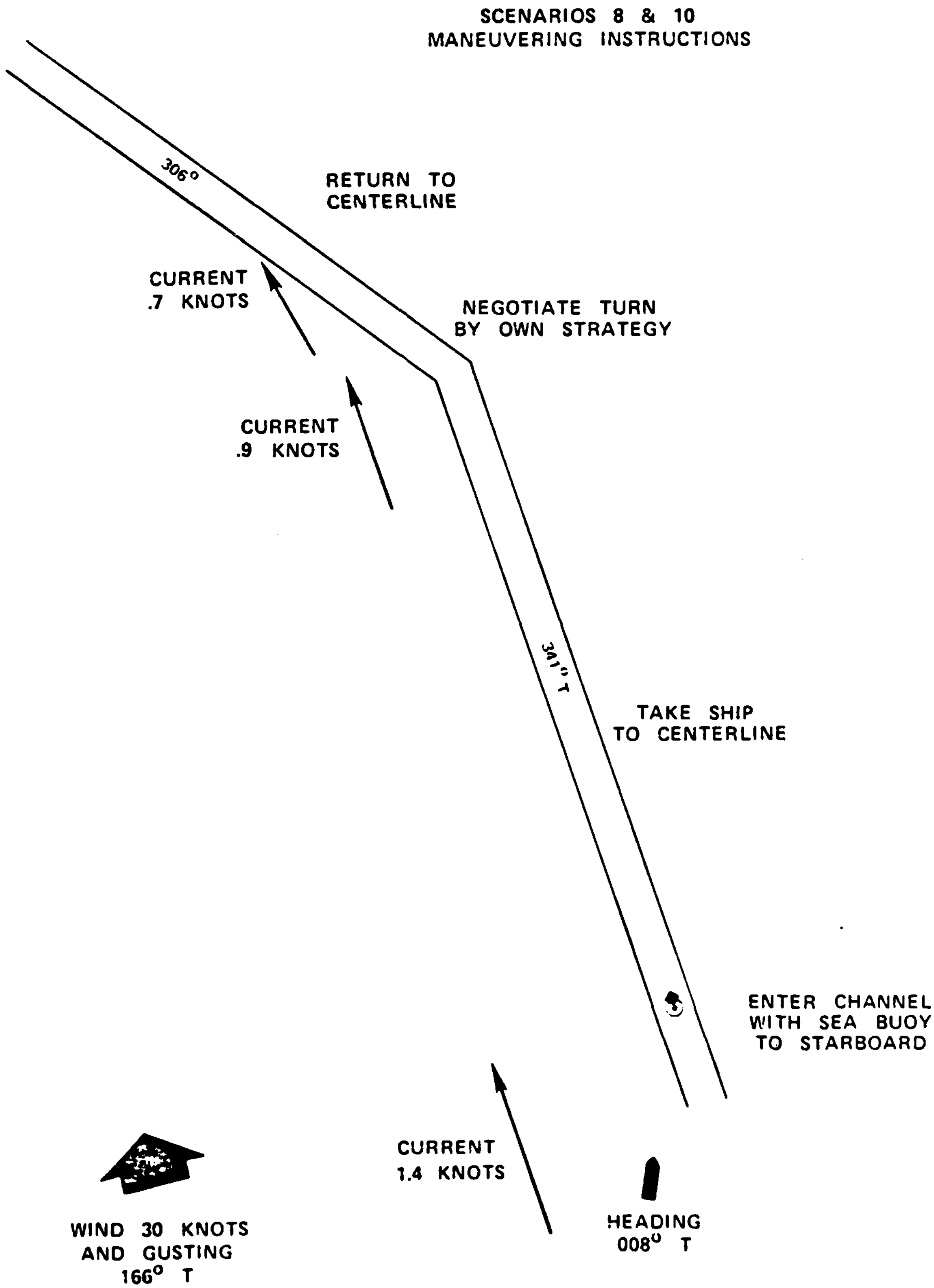


Figure 3. Performance Requirements for Scenarios 8 and 10

SS NEWPORT

DWT	30,000
LENGTH	595 FT
BEAM	84 FT
DRAFT	35 FT

Figure 4. The Characteristics of the 30,000 dwt Tanker

4. The bridge conditions. The pilot had available the following:

- a helmsman to receive his orders
- a gyrocompass
- an engine order telegraph with the opportunity to increase his speed in the turn
- charts of the channel with the course and buoy locations
- a diagram of the current conditions
- no radar (this is an experiment in visual piloting)

The primary piloting attributes of interest in this experiment are the visual piloting skills with which shiphandlers maneuver through the turn and the variables which affect those skills. The use of radar, an instrument that would normally be available in real-life situations was intentionally prohibited for this experiment in order to focus attention on visual piloting skills. Comments reported by the pilots are consistent with this line of thinking. In general, pilots report that they would use radar to judge distance (e.g., distance from a buoy) and use visual cues to judge the ship's rate of swing through the turn. Radar was not believed to be helpful while maneuvering through the turn.

5. The visual scene. The visual scene for the scenarios using the 30,000 dwt tanker is illustrated in Figure 5. The bow of the ship with an eyepoint at midships and 45 feet off the water appears on the center screen. The buoy lights illustrated are those that appear at initialization in Scenario 1. (All the lights are shown, although as flashing lights they would never be seen together. The turn lights are labeled.) Within each scenario, the lights presented at initialization vary in color, flash rate, and location by the requirements of Table 2. Within each scenario, the

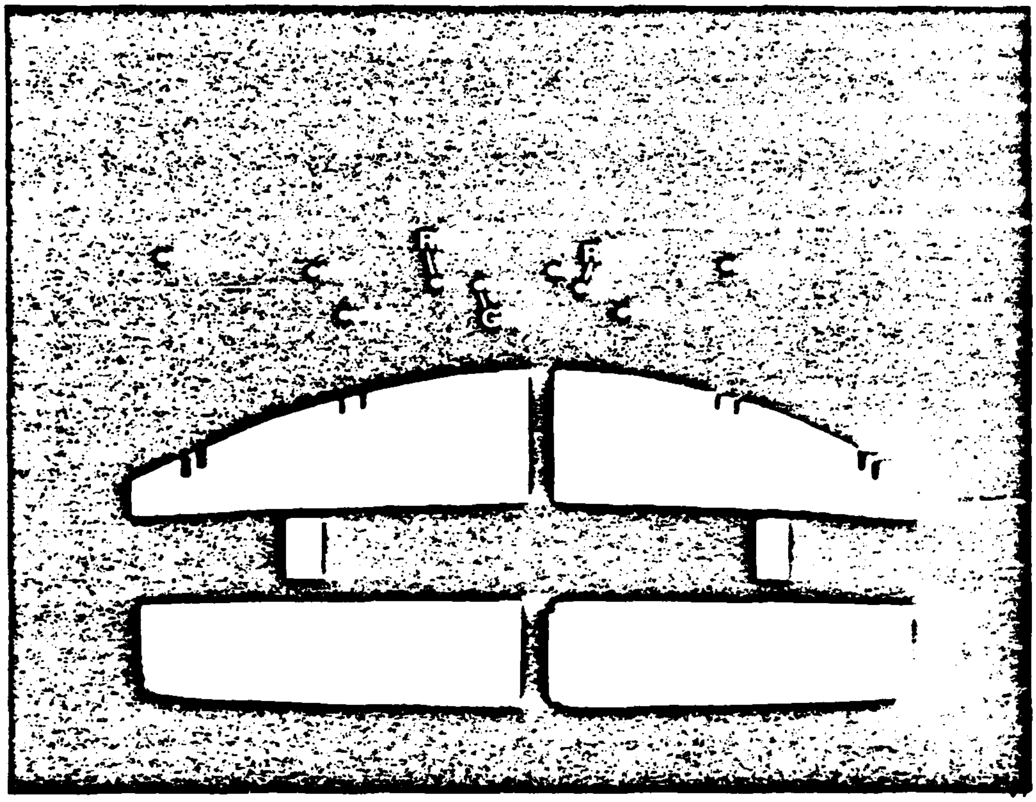


Figure 5. The Visual Scene with the 30,000 dwt Tanker

lights change in location on the screen in response to the ship's motion and disappear behind the bridge wings just before they pass abeam.

1.6 THE PERFORMANCE REQUIREMENTS

The performance requirements for Scenarios 1-7 and 9 are summarized in Figure 2. The ship was initialized 1.8 nm below the turn and 100 feet to the right of the centerline at a speed through the water of 6 knots. At that point there is a following current of 1.2 knots and decreasing and a following wind of 30 knots and gusting. The pilot had time to study the lights ahead and orient himself (a chart was available for this purpose) before it was necessary to maneuver the ship. The pilot was instructed to take the ship to the centerline of the first leg. He could then leave the centerline when ready to negotiate the turn by his own strategy, which might include temporarily increasing the engine rpm. As he entered the new leg, the wind and current were on his port quarter. The current decreased in velocity to 3/4 knots with a crosscurrent component of 1/4 knots. The pilot was asked to bring the ship to the centerline of the new leg. Maintaining the centerline at the beginning of the second leg required a drift angle of approximately 3 degrees, a requirement that decreased as the crosstrack velocity of the current decreased. (The wind maintains its average velocities.) The scenario ends 0.8 nm beyond the turn as the ship passed through

the first gated pair of buoys in the second leg. The elapsed time was approximately 16.5 minutes.

1.7 SPECIAL CONSIDERATIONS FOR THE SHIP SIZE COMPARISON: SCENARIOS 8 AND 10

The second ship was an 80,000 dwt tanker similar to the vessel used in the Ship Variables experiment. This ship is 763 feet long, 125 feet in the beam, with a 40-foot draft (in a channel adjusted to 41 feet). The bridge is a rear house with a viewing point 350 feet back from the center of gravity and 732 feet back from the bow. That viewing point is 80 feet above the water. The information provided for the pilot appears as Figure 6. The bow image for this ship is illustrated in Figure 7.

The need to compare Scenarios 8 and 10 run with the different size ships presented a special problem: the pilots should not be more familiar with the handling characteristics of one ship than the other. If these scenarios were treated like the others, there might be a bias in favor of the 30,000 dwt ship with which the pilots make many more runs. The following arrangements avoided such a bias:

- Scenarios 8 and 10 were the first experimental scenarios run (see Section 1.8.2).
- Scenarios 8 and 10 differed from the others in requiring the pilot to maneuver the appropriate ship into the channel before approaching the turn of interest.

The layout of Scenarios 8 and 10 with the performance requirements is illustrated in Figure 3. (This is similar to the scenarios in the Ship Variables experiment. There was a similar need to ensure the pilot's familiarity with the ship before the turn of interest.) Rather than being initialized inside the channel, the ship was initialized 2400 feet outside the channel with a heading of 008 degrees T. The pilot was instructed to enter the channel to the left of a sea buoy at the center of the channel. The current was running at 1.4 knots parallel to the channel he was about to enter, so it was broad on the starboard quarter as he began the entry into the channel. Once in the channel, the pilot was instructed to take the ship to the centerline. From there the scenario continues in the same way as the others. Elapsed time of Scenarios 8 and 10 was approximately 25 minutes.

1.8 SUBJECTS AND PROCEDURES

1.8.1 Subjects

Nine subjects were recruited from Northeast Marine Pilots, Inc., Newport, Rhode Island. These pilots have recent at-sea experience on similar ships and in similar channels to that which they experienced on the U.S. Coast Guard/EA simulator and the majority of them have participated in some simulator-based research prior to this experiment. One subject participated in presimulation runs that were used to review the scenarios to minimize or eliminate any problems that might occur. Eight pilots participated in the actual experimental runs which took one day per subject.

SS NORTHEAST

DWT	80,000
LENGTH	763 FT
BEAM	125 FT
DRAFT	40 FT

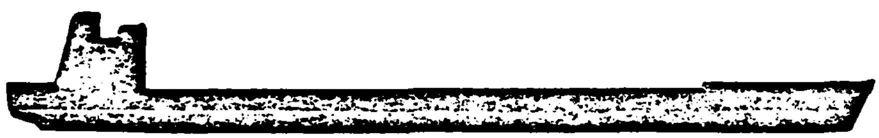


Figure 6. The Characteristics of the 80,000 dwt Tanker

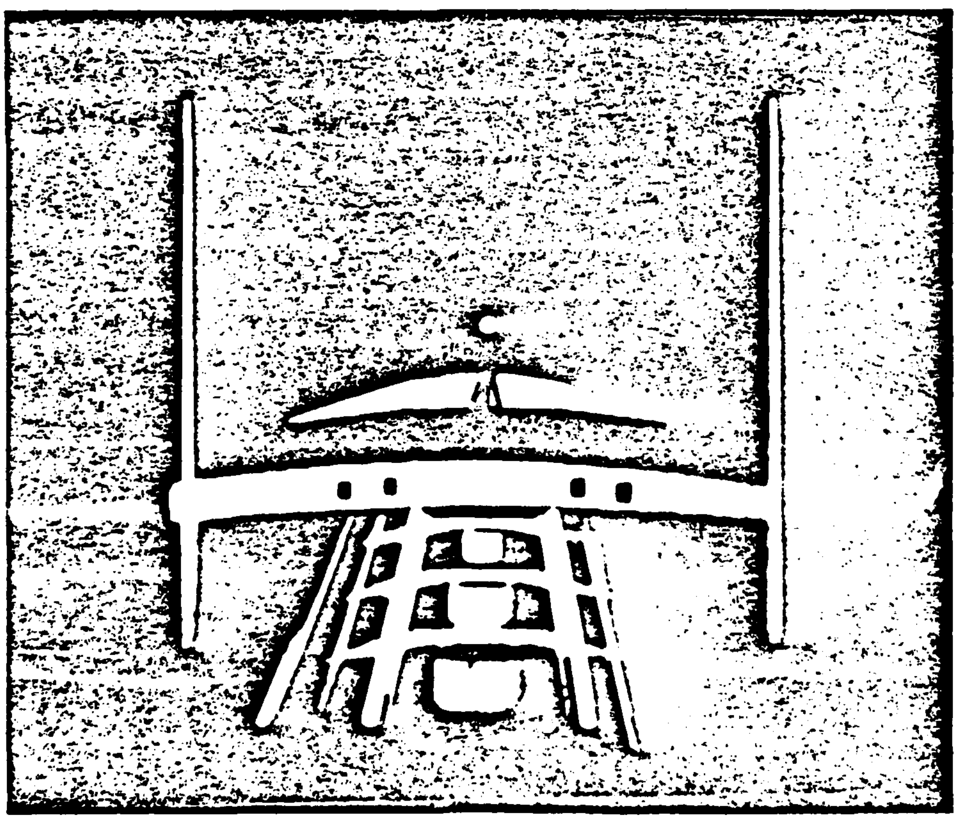


Figure 7. The Visual Scene With the 80,000 dwt Tanker

1.8.2 General Procedures

Each pilot's day consisted of the following events:

1. The briefing included the prepared "Instructions to the Pilot" which appears as Appendix C.

2. Familiarization runs. Each pilot received two familiarization runs to acquaint him with the bridge equipment, visual scene, and shiphandling response of ownship to wind and current effects and other environmental effects without exposure to actual experimental scenarios. The first familiarization scenario was run under daytime conditions using a 30,000 dwt tanker while the second was run under nighttime conditions using an 80,000 dwt tanker. The channel consisted of two straight segments marked by gated buoys and four buoys marking the turn, as illustrated in Appendix A.

3. The ship size comparison (Scenarios 8 and 10) was run after the familiarization run. Isolation of this comparison from the rest of the turns prevented performance bias that might have resulted from the fact that many more runs were made with the 30,000 dwt tanker. These two scenarios are the longer scenarios with the turn into the channel described in Section 1.7. These scenarios also differ from the others by starting at different positions outside the channel (see Appendix A).

4. The remaining experimental runs (Scenarios 1 though 7 and 9) were randomly sequenced to distribute any order effects (learning, fatigue, boredom) equally among the scenarios.

5. The postsimulation questionnaire was informally administered to the pilot. The pilots were encouraged to comment at any time during the day.

1.9 THE PERFORMANCE MEASURES AND DATA ANALYSIS

1.9.1 The Performance Measures

A variety of performance measures were collected for use in evaluating the scenario conditions. They include the following classes:

1. The primary measure, ship's crosstrack position, was recorded as a function of alongtrack position during the transit of the channel. When the ship crossed the data lines illustrated in Figure 8, the ship's position was automatically recorded by the computer along with other related measures.

2. The pilot's course, rudder, and engine orders were recorded by an operator at a computer terminal. The computer added measures of ship's status concurrently with the recording of this data.

3. A postsimulation questionnaire asked for the pilots comments on the conditions of each scenario and his strategies. This questionnaire served as the pilot's contribution to the preliminary observation report prepared immediately after the data collection phase.

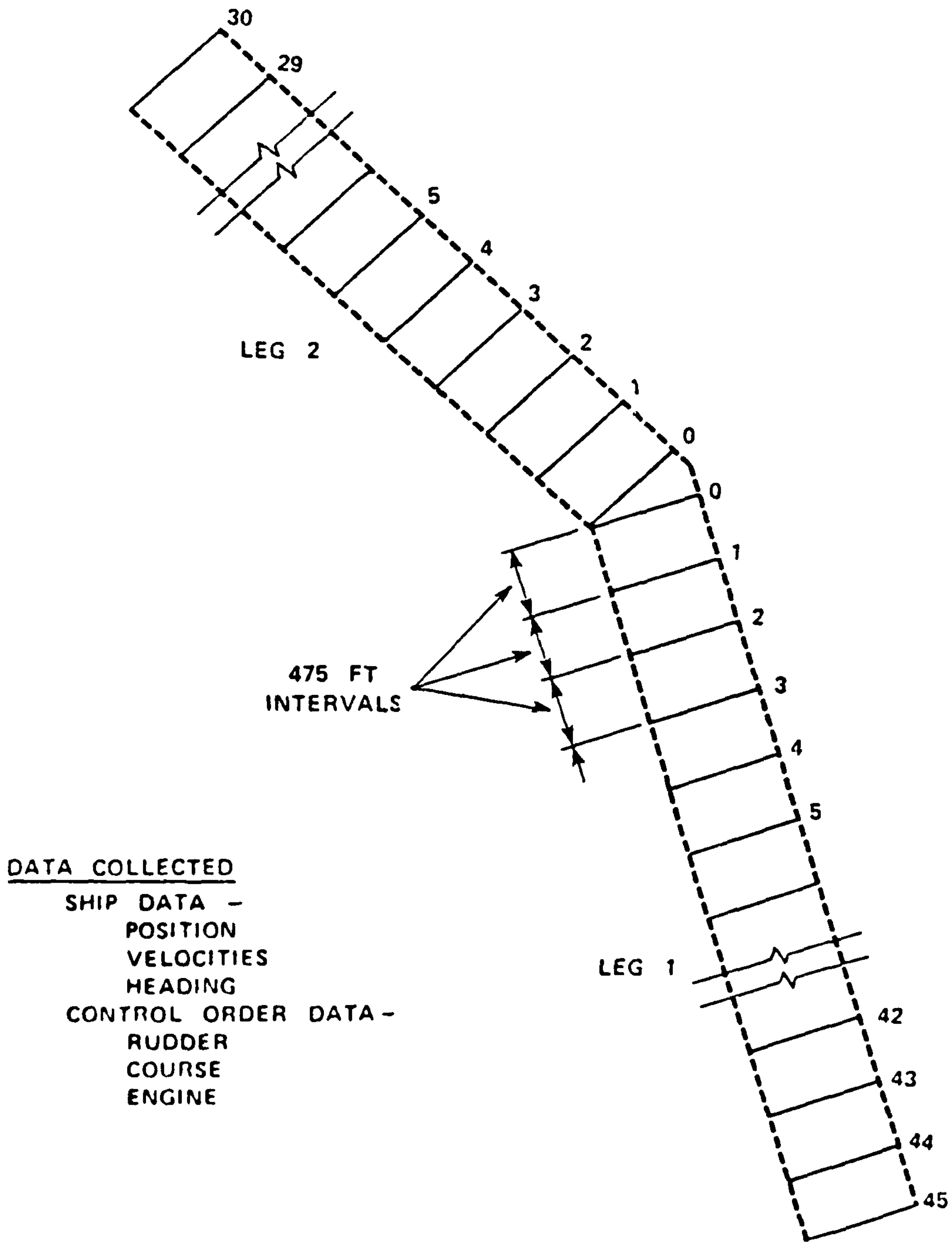


Figure 8. The Data Collection Lines

1.9.2 The Descriptive Analysis of the Primary Data

The principal descriptive analysis is a compilation of data on the position of the ship's center of gravity. The basic measure of the ship's crosstrack position is treated as illustrated in Figure 9. The crosstrack mean and standard deviation of the eight runs made were calculated at each data line for the set of experimental conditions to be analyzed. The first set of axes shows the means; the second, the standard deviation. The last set of axes is a "combined plot" which shows the envelope formed by the mean and two standard deviations to either side of it against the boundaries of the channel. The envelope encloses 95 percent of expected transits under the experimental conditions sampled. The placement (mean) and width (standard deviation) of this envelope within the boundaries of the channel comprise a quantitative description of the set of transits for a particular buoy arrangement.

The trackkeeping portions of the scenario are the easiest to interpret. It is assumed that, because of instructions, the pilots attempted to keep the ship on the designated track. The distance for a particular mean off the centerline and the spread measured by the standard deviations are indications of the performance for a particular buoy arrangement under the conditions sampled. Ideally, the best buoy arrangement is one that puts the mean of the distribution on the trackline and minimizes the standard deviation. Performance in the turn is more difficult to interpret. The distribution of crosstrack positions in the maneuvering portions contains the variations in pilots' strategies as well as the performance of the buoys in guiding them in those strategies. An adequate buoy arrangement should keep the combined plot well inside the channel.

Implicit in this discussion is the assumption that the precision in piloting performance that a buoy arrangement affords, is related to the safety of that channel: a safely-marked channel is one that results in a distribution of transits that is well within the channel boundary for both trackkeeping and maneuvering. It should be reemphasized that these measures are derived from an experiment and not a real-world situation. They are measures of performance under the experimental conditions (the experimental design and the simulation) used. For application to real-world channels, they must be considered relative measures of the performance of buoy arrangements or channel conditions. The interpretation of these performance measures as probability of grounding, for example, would be incorrect pending validation of such interpretation in the real world.

1.9.3 Inferential Analysis of the Data

The use of inferential tests takes into account the following considerations. Analysis of the data is dictated by the experimental conditions being compared (see Table 3). It may take one of two forms depending upon the question to be answered:

1. Exhaustive tests for the scenarios being compared at each data line.

2. Tests that focus on only critical data lines for the scenarios being compared.

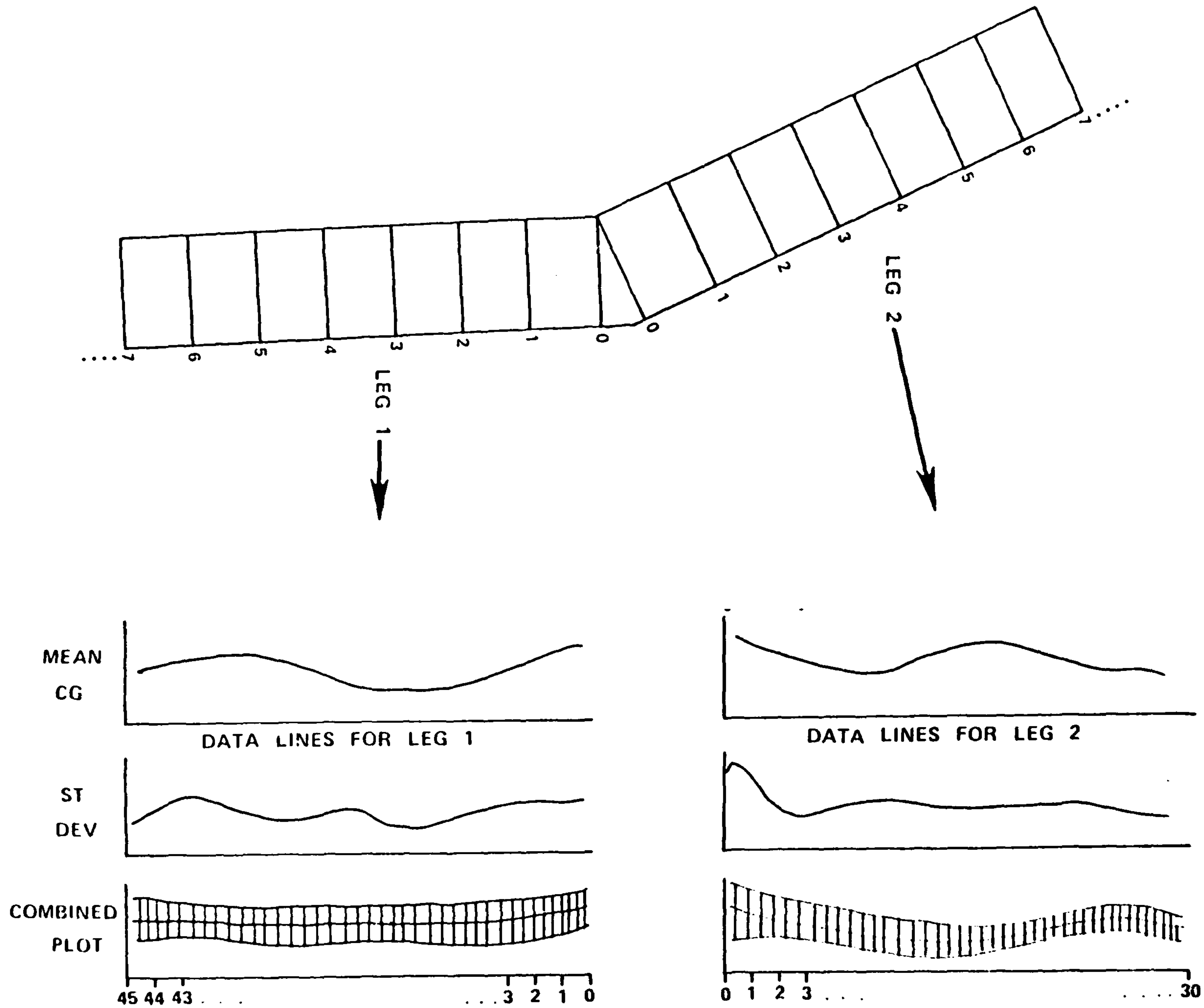


Figure 9. Descriptive Analysis of Ship's Center of Gravity Data

Analysis of the data used both the mean and standard deviation as described in Section 1.8.2. These tests were done using the following procedures as described in McNemar.[13]

The means:

- When means from two conditions were compared, a t-test was used.

The standard deviations:

- The standard deviation of the conditions was compared in pairs according to the comparisons in Table 3. They were compared as variances, using variance ratios, or an F-test.

[13]Quinn McNemar. Psychological Statistics. Fourth Edition. New York: John Wiley and Sons, Inc., 1969.

SECTION 2

PERFORMANCE AS A FUNCTION OF DAY/NIGHT

2.1 INTRODUCTION

This experiment was not specifically designed to compare the effects of day/night differences on performance. However, the experimental conditions have been designed such that certain nighttime scenarios can be compared to similar scenarios from two previous experiments, the One-Side Channel Marking experiment and the Ship Variables experiment. The constant conditions are similar enough to permit comparison between scenarios that differ primarily on the basis of whether they were run under daytime or nighttime conditions.

2.2 THE EFFECT OF DAY/NIGHT DIFFERENCES IN THE TURN

An assumption was made, prior to the beginning of this experiment, that the best piloting performance in the turn would occur under daylight conditions, where the pilots have the greatest amount of visual information available for making piloting decisions. In this situation, the pilots choose to make the most gradual maneuver possible using the right-hand side of the channel as a boundary in Leg 2. Scenario 1 from the One-Side Channel Marking experiment illustrated in Figure 10, shows the mean track performance for a 35-degree noncutoff turn marked by three buoys. The plot shows a mean track that exits the turn to the right of the centerline with a small standard deviation relative to a comparable nighttime scenario.

Under nighttime conditions, pilots appear to use a different strategy. The comparable nighttime scenario from the Turn Lighting experiment, illustrated in Figure 10, shows a mean track that exits the turn closer to the left edge of the centerline and a standard deviation larger than Scenario 1 of the One-Side Channel Marking experiment. Figures 11A and 11B, showing the distribution of helm orders and where they were made in the channel, indicates that the ship is more often to the left of the centerline in the nighttime than in daylight. At night, pilots are less certain about both the position of ownship in relation to the channel edges. Making a more severe turn and staying closer to the center of the channel decreases the likelihood of going out of the channel and increases the margin of safety in terms of distance from the channel edge. There is a price paid for this strategy, however, in the loss of reserve rudder and maneuvering space remaining to the inside of the channel for emergency situations. Nighttime performance shows a larger standard deviation compared to the daytime scenario shown in Table 5. This may reflect either a greater uncertainty about where the channel edge is or decisions as to what represents an adequate margin of safety with respect to the channel edge. The lack of visual cues normally available to aid navigation in the daytime are either not available or are available in an impoverished form. It is suggested that pilots compensate for this deficiency by adopting the conservative strategy just described.

Day/night differences are also reflected in differences in the type of helm orders. Figures 11A and 11B illustrate differences in helm orders for the daytime and nighttime scenarios. Pilots in the nighttime scenario

TABLE 5. CROSSTRACK MEAN AND STANDARD DEVIATION IN FEET FOR THREE-BUOY AND TWO-BUOY ARRANGEMENTS AND DAY/NIGHT DIFFERENCES

	DAY (ONE-SIDE)				NIGHT (TURN LIGHT)			
	SCENARIO	DATA LINE	MEAN	STANDARD DEVIATION	SCENARIO	DATA LINE	MEAN	STANDARD DEVIATION
THREE BUOYS	1	2	37R*	32	1	2	8R	56
TWO BUOYS	6	3	94R	33	8	3	22R	81
THREE BUOYS (POOLED)					1–6	2	6R	46
TWO BUOYS (POOLED)					8,9	3	28R	67

* MEAN IS EXPRESSED IN FEET TO RIGHT OF CENTERLINE

tended to give more rudder orders compared to course orders as they moved through Leg 2. In the daytime scenario, pilots tended to give a larger number of course orders compared to rudder orders through Leg 2. This was true for both three-buoy and two-buoy arrangements. The greater number of rudder orders in the nighttime scenario allows the pilot to maintain a greater control over the ship's heading, by maintaining direct control over both magnitude of the rudder and when the rudder command is executed.

The two strategies used by the pilots should not be thought of as discrete, separate approaches to piloting. Rather, these strategies lay on a continuum. Under nighttime conditions, Scenario 1 with three quick-flash buoys most closely approximates the daytime strategy. Flash rates slower than quick flash accentuate this nighttime piloting behavior. A comparison of the helm orders between the daytime scenario and the combined Scenarios 1-6 all of which are three-buoy arrangements, illustrates this behavior in Figures 12A and 12B. The rudder and course orders show pilots farther to the left of the centerline in Leg 2 of the nighttime scenario than in the daytime scenario. As the condition which most closely approximates daytime conditions, the three-buoy quick-flash condition provides the best information about rate of turn into a new channel segment and location of the outside channel edge. Flashing at a faster frequency, it is easier to detect than either the slower 2.5 second and 4.0 second flash rates. In addition, identification, and quantification are also easier with quick

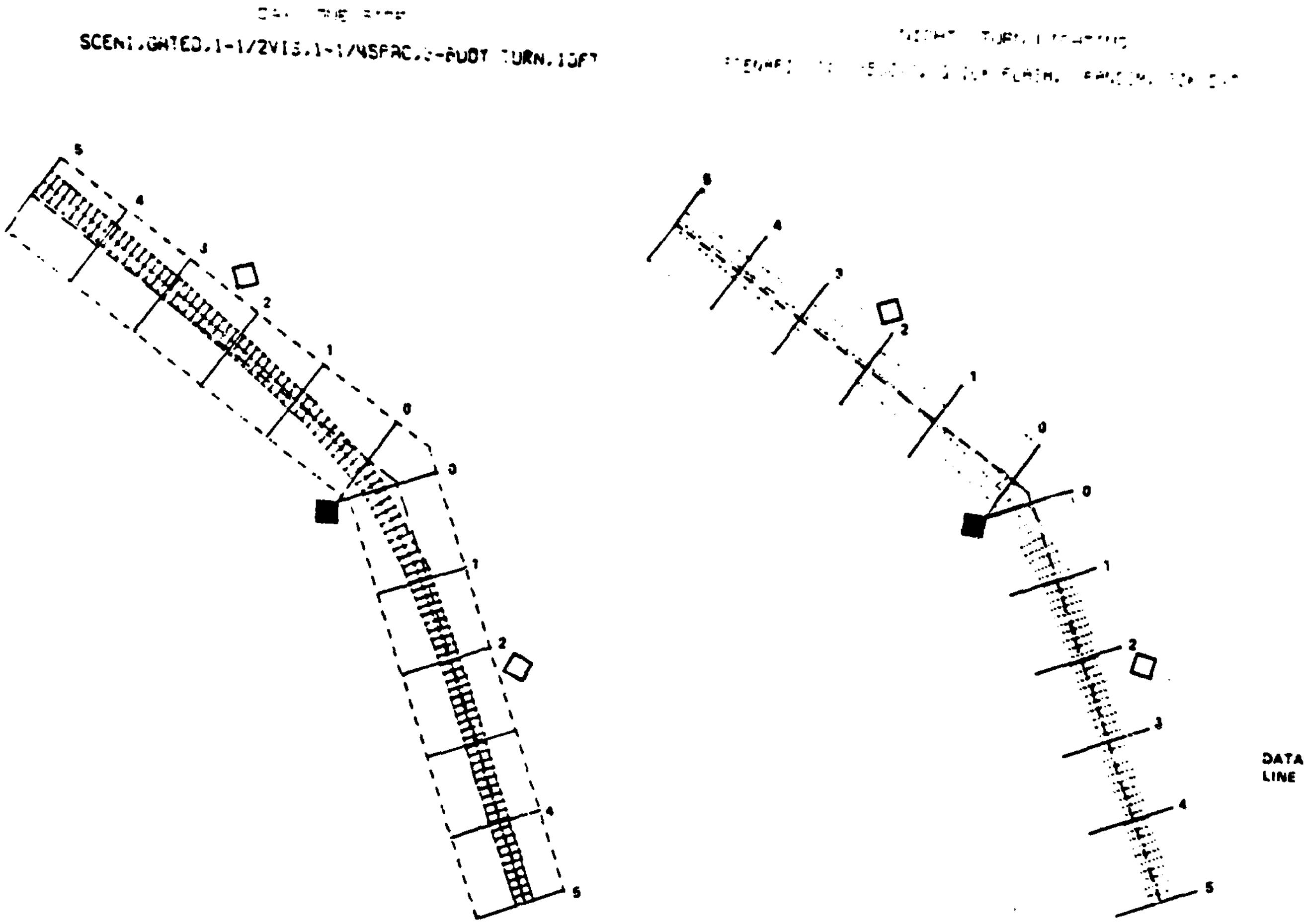


Figure 10. Turnplot Comparison of Day/Night Performance in a Three-Buoy Turn.

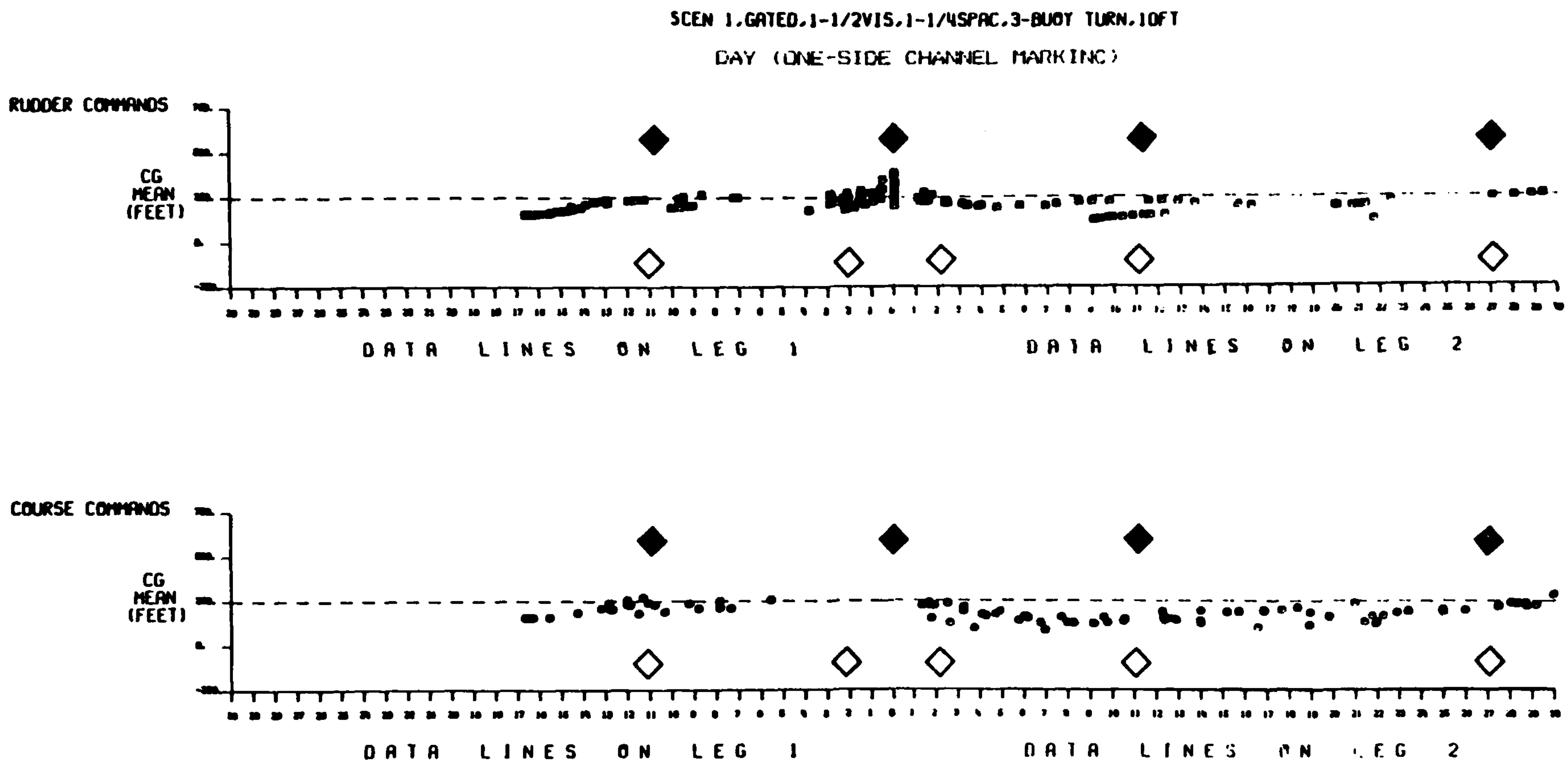


Figure 11A. Daytime Distribution of Helm Orders.

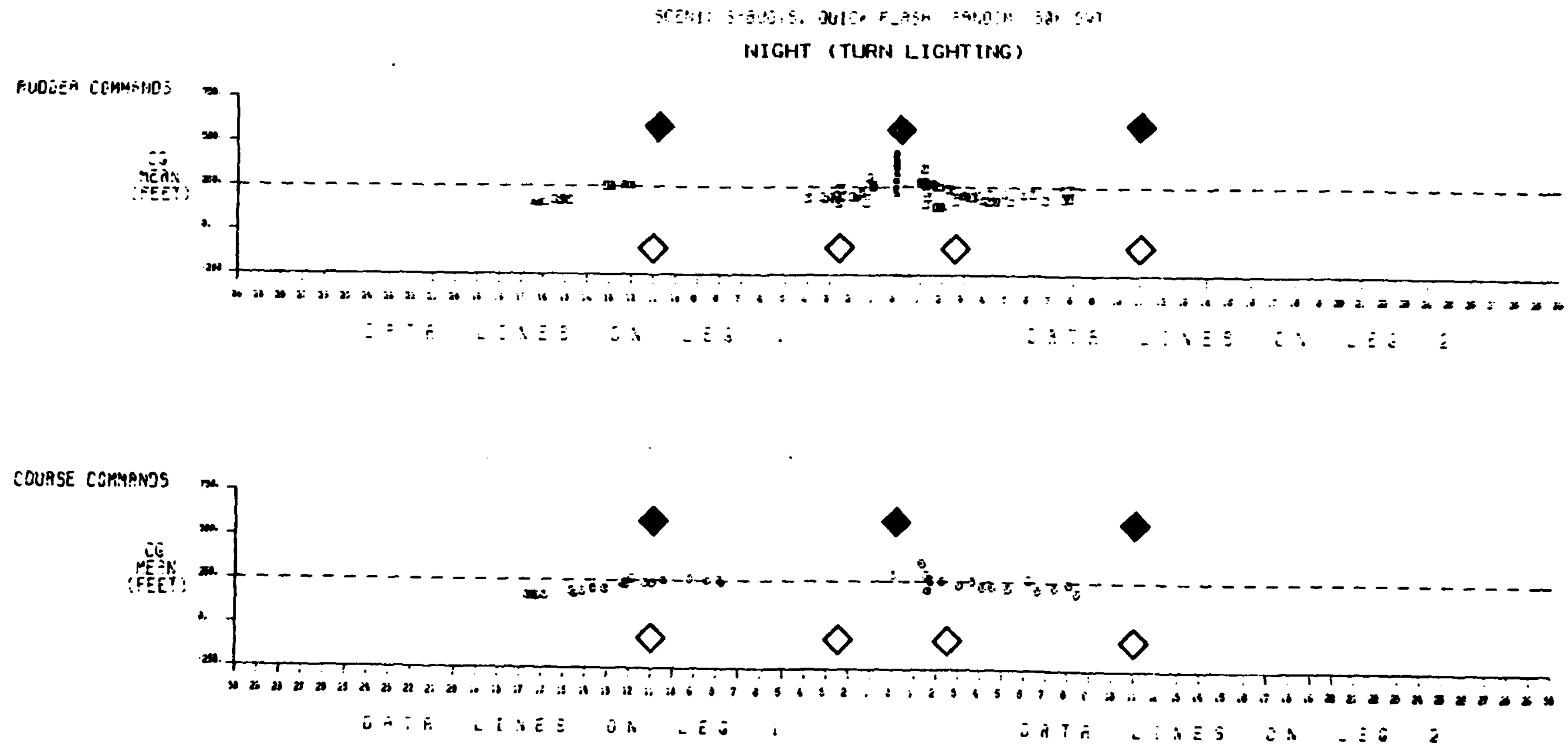


Figure 118. Nighttime Distribution of Helm Orders.

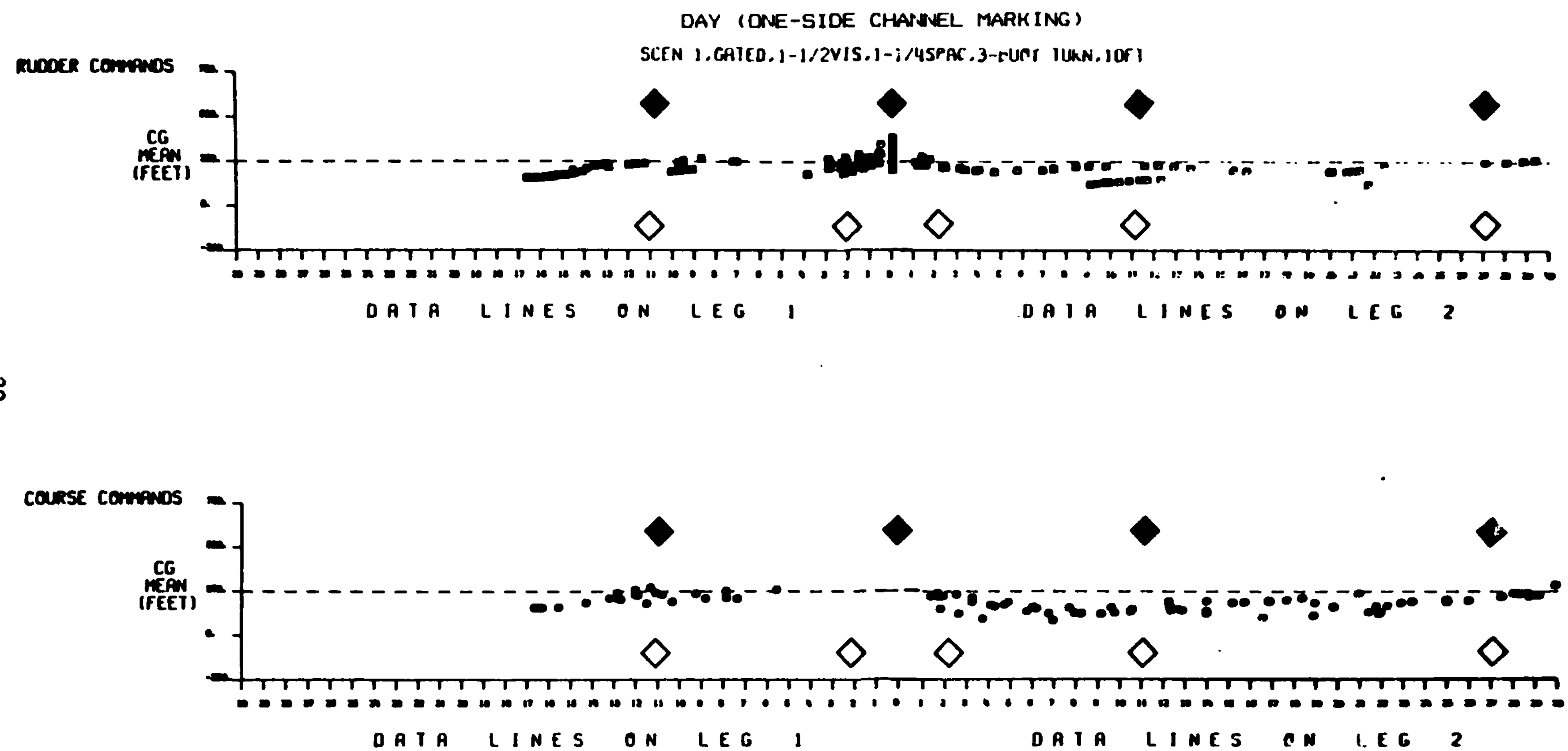


Figure 12A. A Daytime Distribution of Helm Orders.

NIGHT (TURN LIGHTING)

3-BUOYS IN TURN (SCENARIOS 1-6 POOLED)

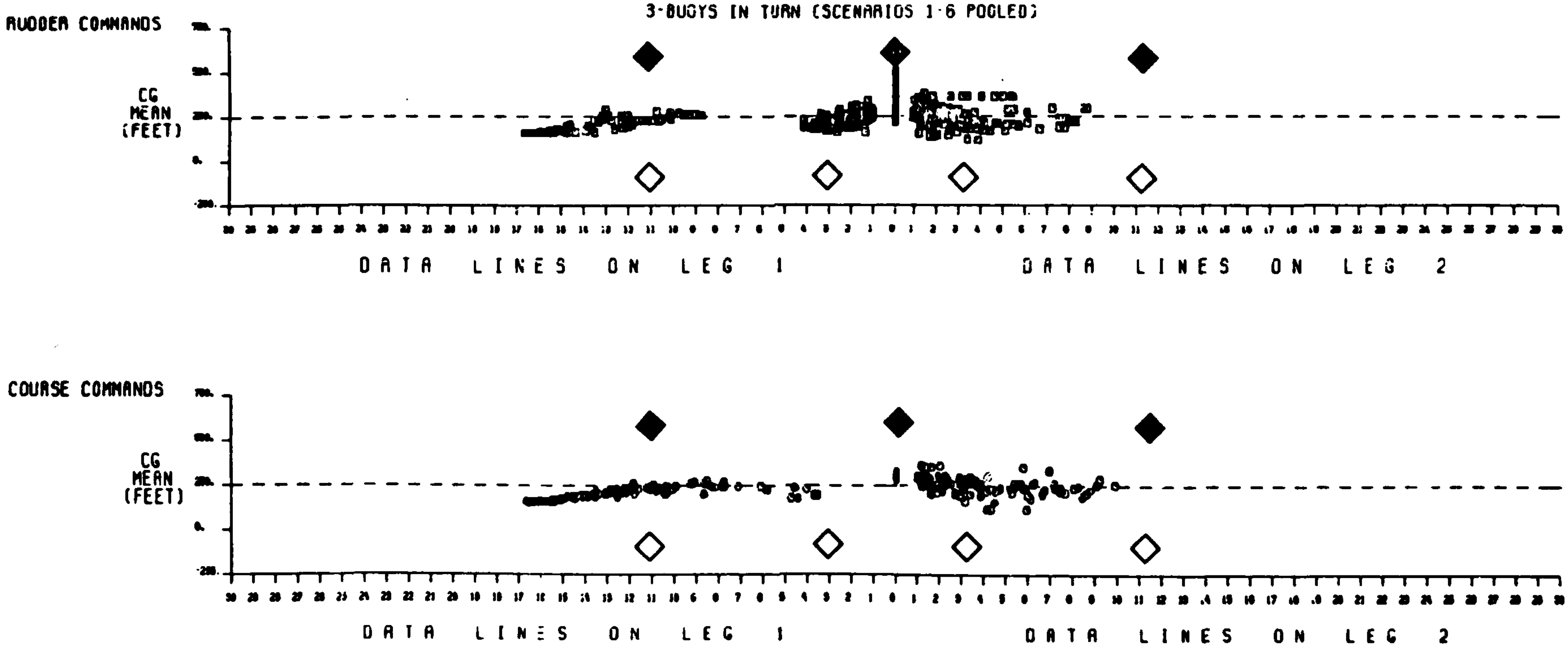


Figure 12B. Distribution of Helm Orders for Pooled Nighttime Scenarios.

flash. Based upon this logic, it is hypothesized that occulting lights (which were not tested in this experiment) should result in performance similar to the quick flash condition. Because the total duration of light is greater than the total duration of darkness, it more closely approximates daytime conditions than quick flash and performance should reflect this daytime strategy. Consequently, pilots could perform as well or better in a channel marked with occulting lights.

The two-buoy conditions show similar nighttime patterns to the three-buoy conditions. Scenario 6, the daytime condition from the One-Side Channel Marking experiment is comparable to Scenario 8 in the present experiment as shown in Figure 13. As in the three-buoy condition, pilots maneuvered much more gradually through the turn in the daytime condition than in the nighttime scenario. Day/night differences in performance do not appear to change as a function of buoy arrangement. The slow-flashing straight channel buoys do not compensate for the lack of a pullout buoy, as do the daytime buoys. Just as in the three-buoy turn, the nighttime two-buoy arrangements fail to provide the set of rich visual cues available in the daytime. Scenario 6 shows a mean that is closer to the centerline (see Table 5) and a larger standard deviation suggesting a greater uncertainty about position in the channel. The distribution of helm orders showing the position of ownship in the channel verifies these two strategies.

2.3 DAY/NIGHT DIFFERENCES IN THE APPROACH

In this experiment, the initialization and channel markings in Leg 1 of Scenarios 8 and 10 were different from the other scenarios. Beginning outside of the channel, the pilots had to maneuver into channel Leg 1 using a flashing Morse alpha sea buoy before preparing to maneuver through the turn. The Ship Variables experiment also ran a series of daytime conditions similar to Scenarios 8 and 10. These are illustrated in Figures 14 and 15. Consistent with the day/night performance differences in the turn, the daytime conditions in the Ship Variables experiment resulted in superior performance, maneuvering into the channel, over the nighttime performance. In each case, the nighttime scenarios come considerably closer to going out of the channel. This may be due to the fact that the pilots are maneuvering into the channel using the sea buoy, with long intervals between flashes. This Morse-alpha flash is analogous to the slow flash used in maneuvering in the turn of Scenario 3. The difficulty in maneuvering on a 4-second flash sea buoy in the approach provides additional evidence against using slow flash rates in the turn.

2.4 CONCLUSION

From the previous discussion, it can be concluded that pilots use a different strategy depending upon the amount of visual information available to guide them through a turn. Pilots in the daytime condition make a more gradual maneuver and, within this group, their performance is more consistent than pilots in the nighttime condition. In the daytime, the visual information necessary to guide pilots is available in both higher quality and quantity than in the nighttime. Pilots in the daytime condition can afford to make a more gradual maneuver, coming closer to the channel edge, but using less rudder. They can judge more accurately the rate of swing,

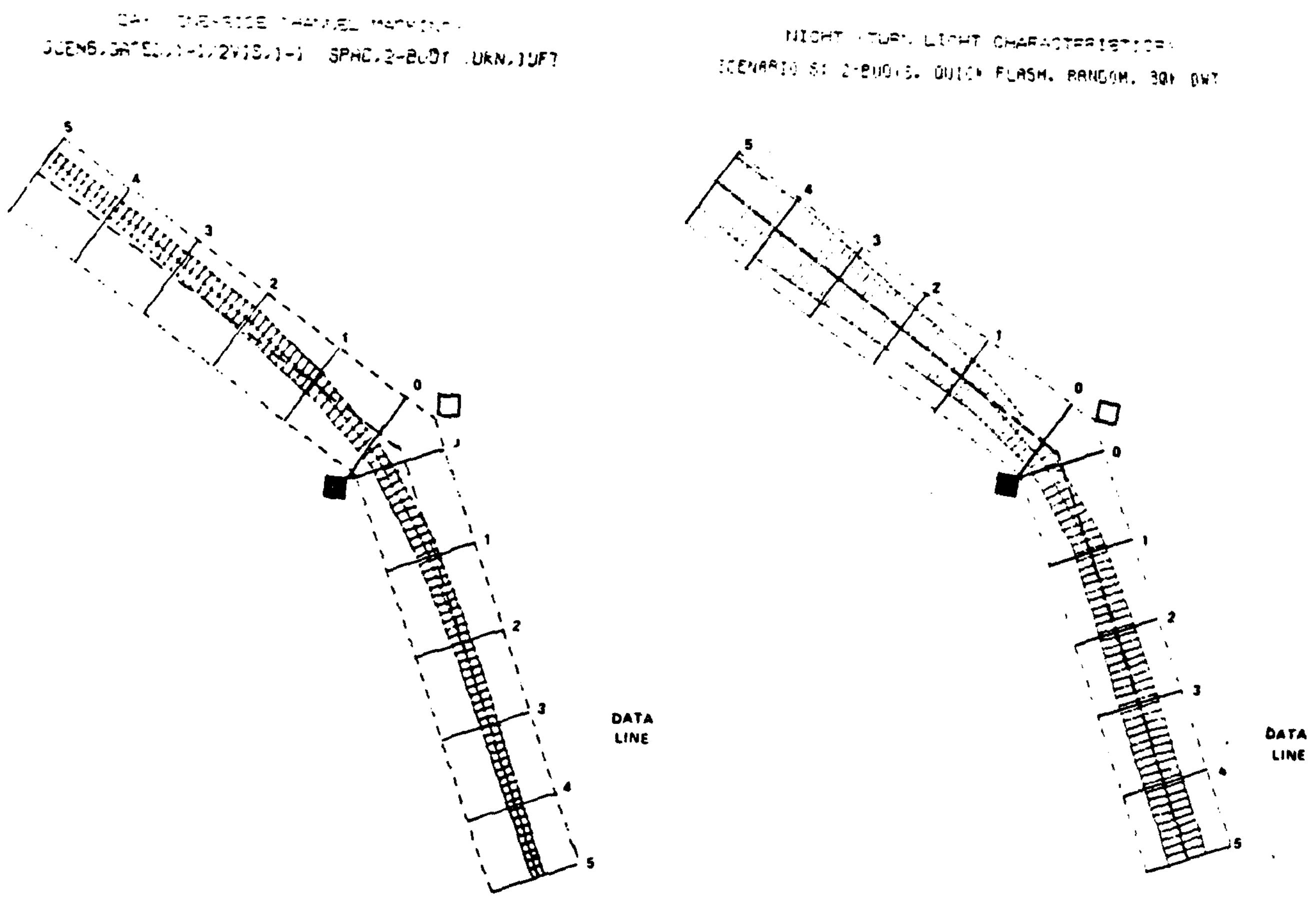


Figure 13. Turnplot Comparison of Day/Night Performance in a Two-Buoy Turn.

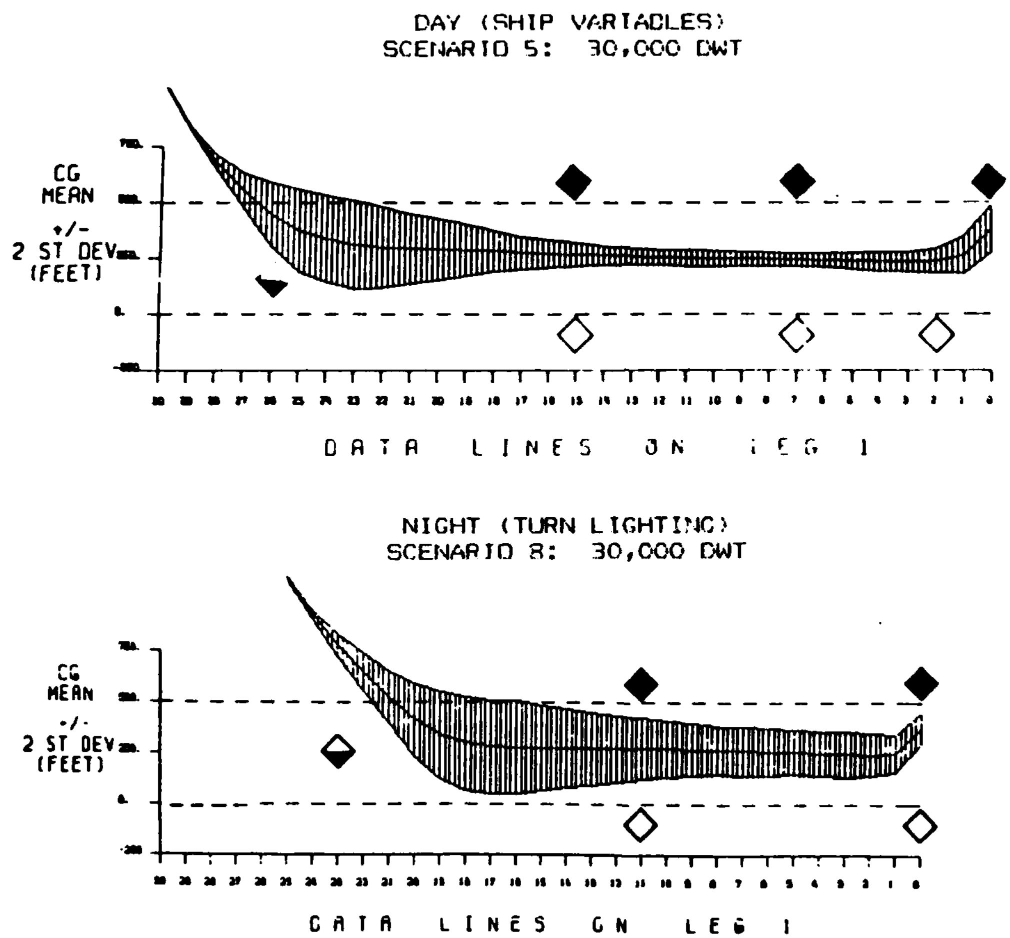


Figure 14. Comparison of Day/Night Performance for Maneuver into Leg 1 With a 30,000 dwt Tanker.

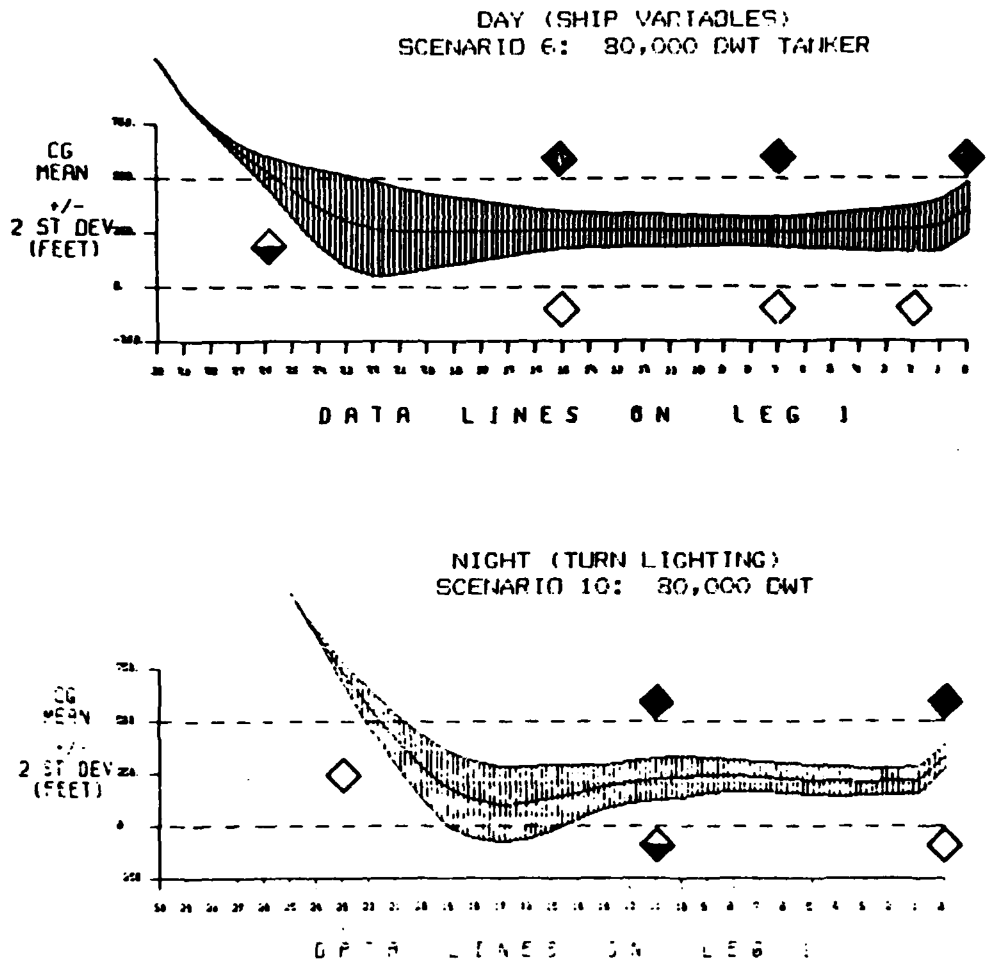


Figure 15. Comparison of Day/Night Performance for a Maneuver into Leg 1 with a 80,000 dwt Tanker.

the channel edges and the relationship of ownship to those channel edges. By contrast, the visual information in the nighttime condition is impoverished. Pilots compensate by adapting a more conservative strategy. They attempt to stay closer to the center of the channel and use more rudder to increase their margin of safety from either channel edge. Impoverished visual information makes it more difficult to judge the rate of swing location of channel edges and relationship of ownship to the channel edge. This translates into group performance with a larger standard deviation. The difference in day/night performance is not a dichotomous effect, but reflects a continuum of difficulty. Within the nighttime conditions, performance ranges from behavior that approximates the daytime strategy to piloting behavior that represents the more conservative nighttime strategy.

Two sets of recommendations follow from the observed performance differences. The most obvious recommendations are operational: that high risk operations, those that involve large ships, dangerous cargo, and/or take place in poorly marked channels, take place under daytime conditions. In terms of design of turn marking arrangements, the observed differences suggest that if a channel is to be marked for nighttime operations, it should be marked conservatively. "Conservatively" might mean with more buoys rather than fewer buoys. Section 4.4 discusses numbers of buoys in the turn for a variety of conditions. There was also a suggestion in this section that conservative nighttime marking might mean quick flash. Flash rate and its effects on performance is further discussed in Section 3.

SECTION 3

EFFECTS OF LIGHTING CHARACTERISTICS ON PERFORMANCE IN THE TURN

3.1 INTRODUCTION

Three flash rates -- quick flash, 2.5-second flash, and 4-second flash -- were compared to evaluate the effects of flash rate on piloting performance in the turn. In addition to evaluating the overall effect of flash rate in the turn, the effects of flash rates for the turnpoint buoy and the pullout buoy were examined to determine their role in aiding navigation. Synchronization was evaluated with respect to slower flash rates.

3.2 THE EFFECTS OF FLASH RATE IN THREE-BUOY TURNS

A comparison of the three flash rates in this experiment reinforces the point made earlier in Section 2 that quick-flash buoys in the turn result in piloting performance that is most like the daytime strategy. This point is illustrated graphically in Figures 16A and 16B comparing quick flash to the 2.5-second flash rate. Coming out of the turn, Leg 2 shows statistically significant differences in performance. The crosstrack mean for the quick-flash group is more gradual, moving further to the right channel edge than the 2.5-second flash rate condition. The crosstrack standard deviation is considerably smaller for the quick-flash group suggesting that they are more certain where they are in the channel and where the channel edges are located than the 2.5-second flash group. When given a choice, pilots prefer quick flash over both the 2.5-second and 4-second flash rate. The pilots describe quick flash as easier to pick out against the background during the approach and easier to concentrate on while going through the turn than either of the two slower flash rates.

At flash rates slower than quick flash, there are no meaningful differences. The inability of pilots to use the 2.5-second flash rate more effectively than the 4-second flash rate is reflected in the pilots comments as well. Some pilots believed the 2.5-second flash rate was easier to pick out against the background than the 4-second flash rate while others did not. Figures 17A and 17B compare the 2.5-second flash group to the 4.0-second flash group for a three-buoy turn. Although there are statistical differences, they are not practically meaningful. Performance in both flash rate conditions reflect the nighttime strategy. It is evident from the large standard deviations in both conditions that pilots have difficulty in recovering from the turn. The fact that the standard deviation continues to increase is probably due to wind and current effects as well as recovery from the turn. The pilots, thus, appear to have more difficulty recovering from a poorly marked turn than from a well-marked turn.

3.3 LIGHTING CHARACTERISTICS FOR THE TURNPOINT AND PULLOUT BUOYS

Although all the pilots wanted at least one quick-flash buoy in every turn, most pilots did not care whether the other turn buoys were quick flash or not. Given only one quick-flash buoy, eight out of nine pilots would place it on the apex of the turn. Comparison between Scenarios 1 and 4 (Figures 18A and 18B) bears out the pilots' feeling that quick flash is most

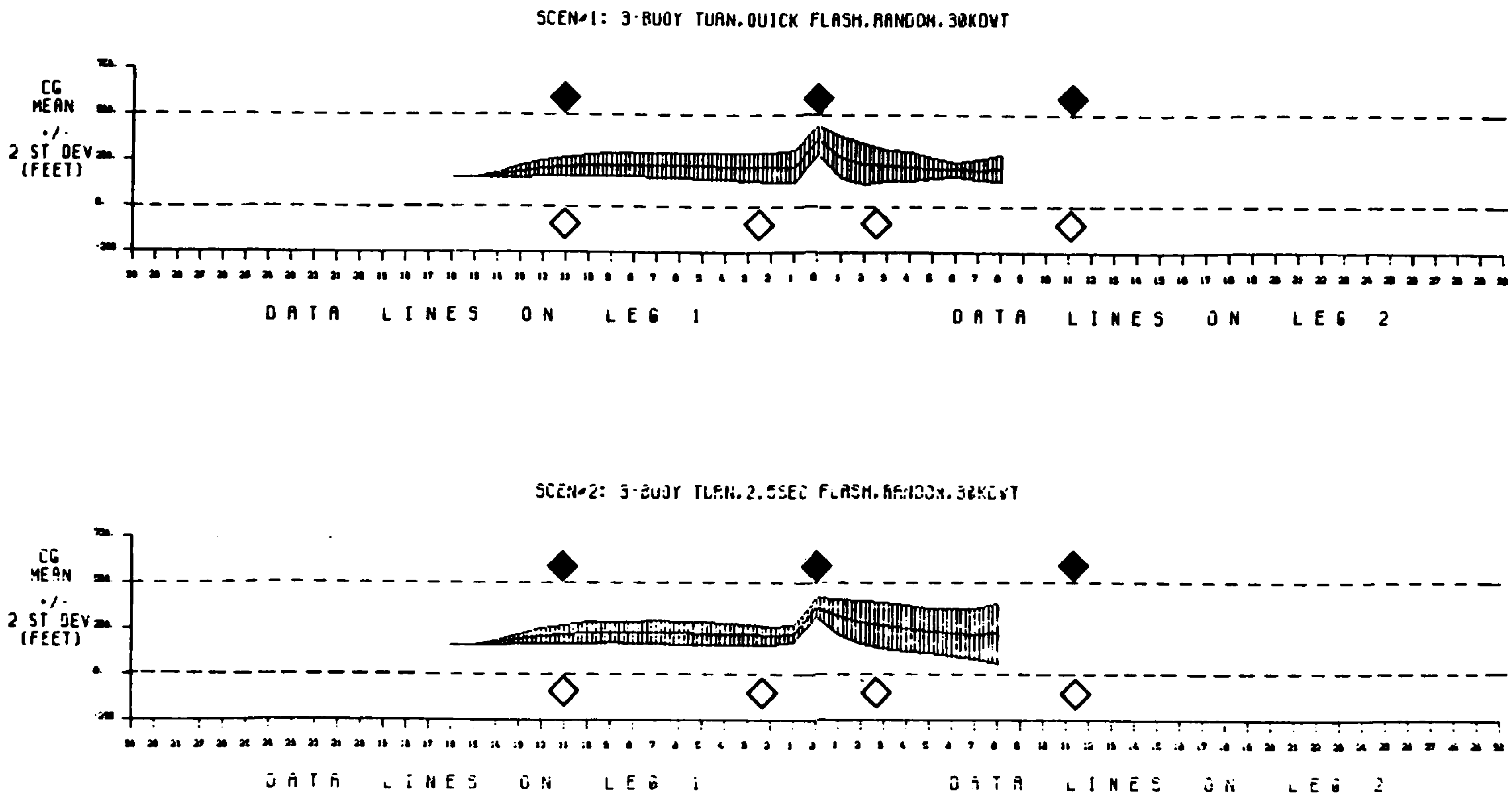


Figure 16A. Combined Plots for Flash Rate in Three-Buoy Turn (Quick Flash Versus 2.5 sec.).

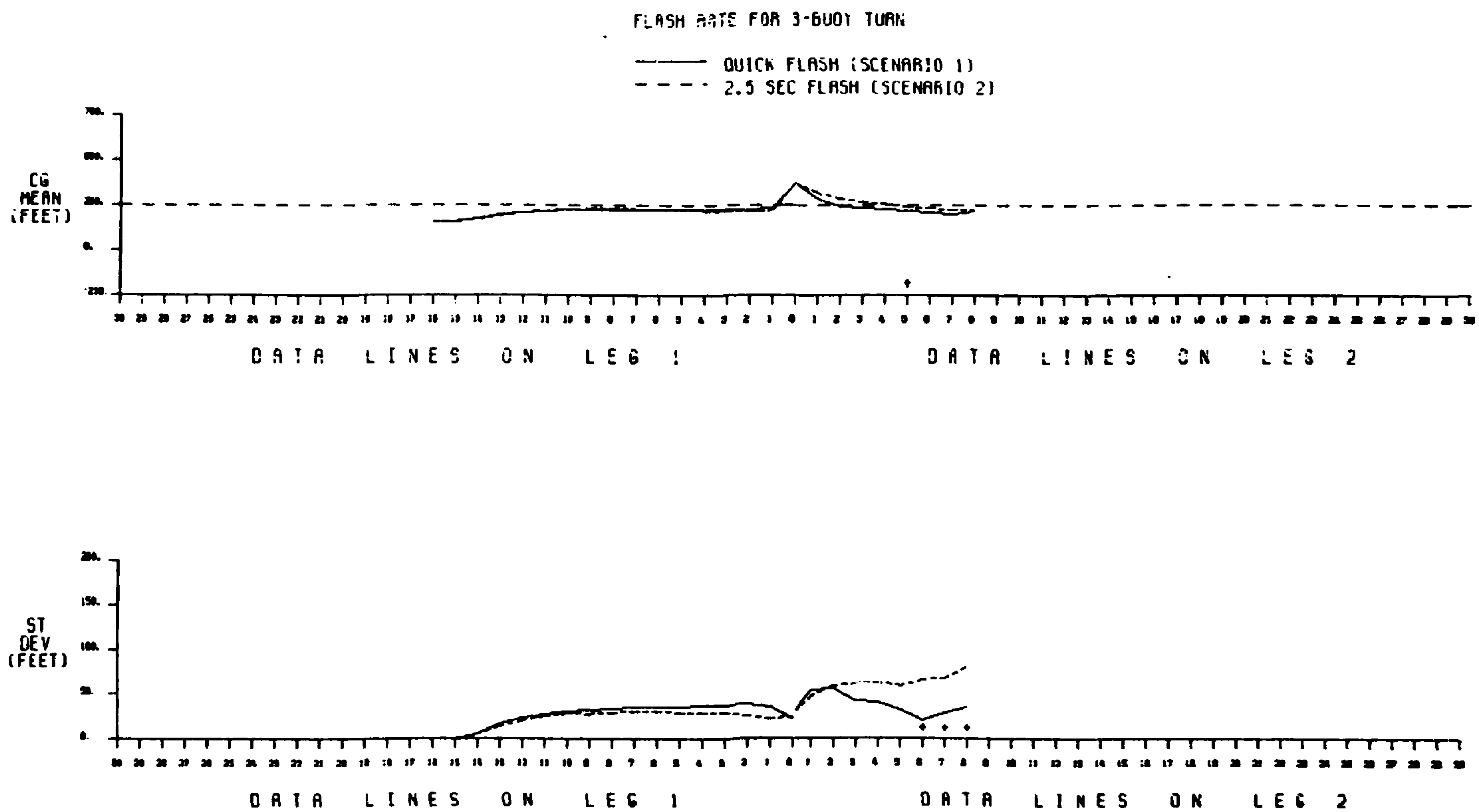


Figure 16B. Comparison Plcts for Flash Rate in Three-Buoy Turn (Quick Flash Versus 2.5 sec.).

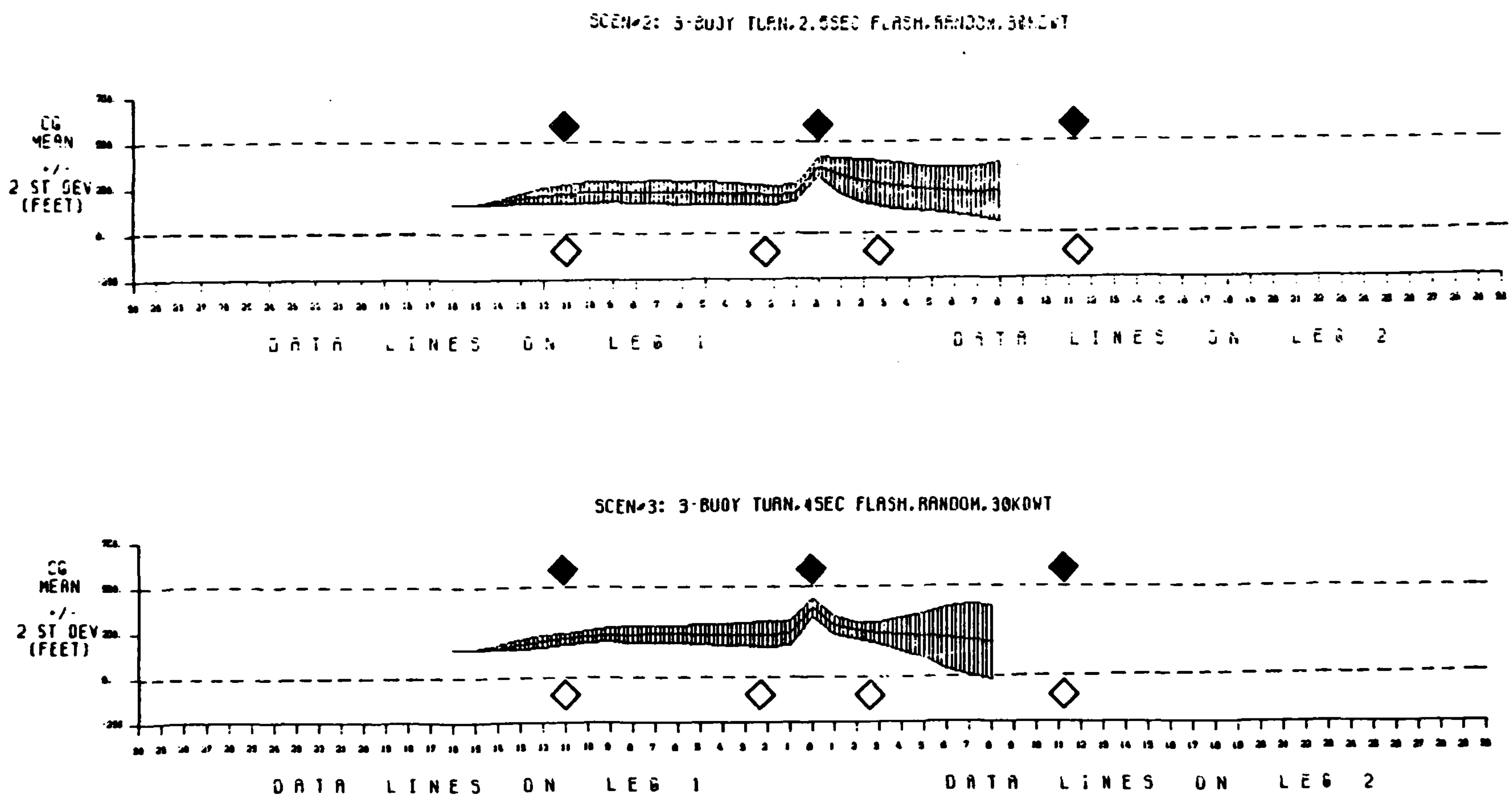


Figure 17A. Combined Plots for Flash Rate in Three-Buoy Turn (4 sec. versus 2.5 sec.).

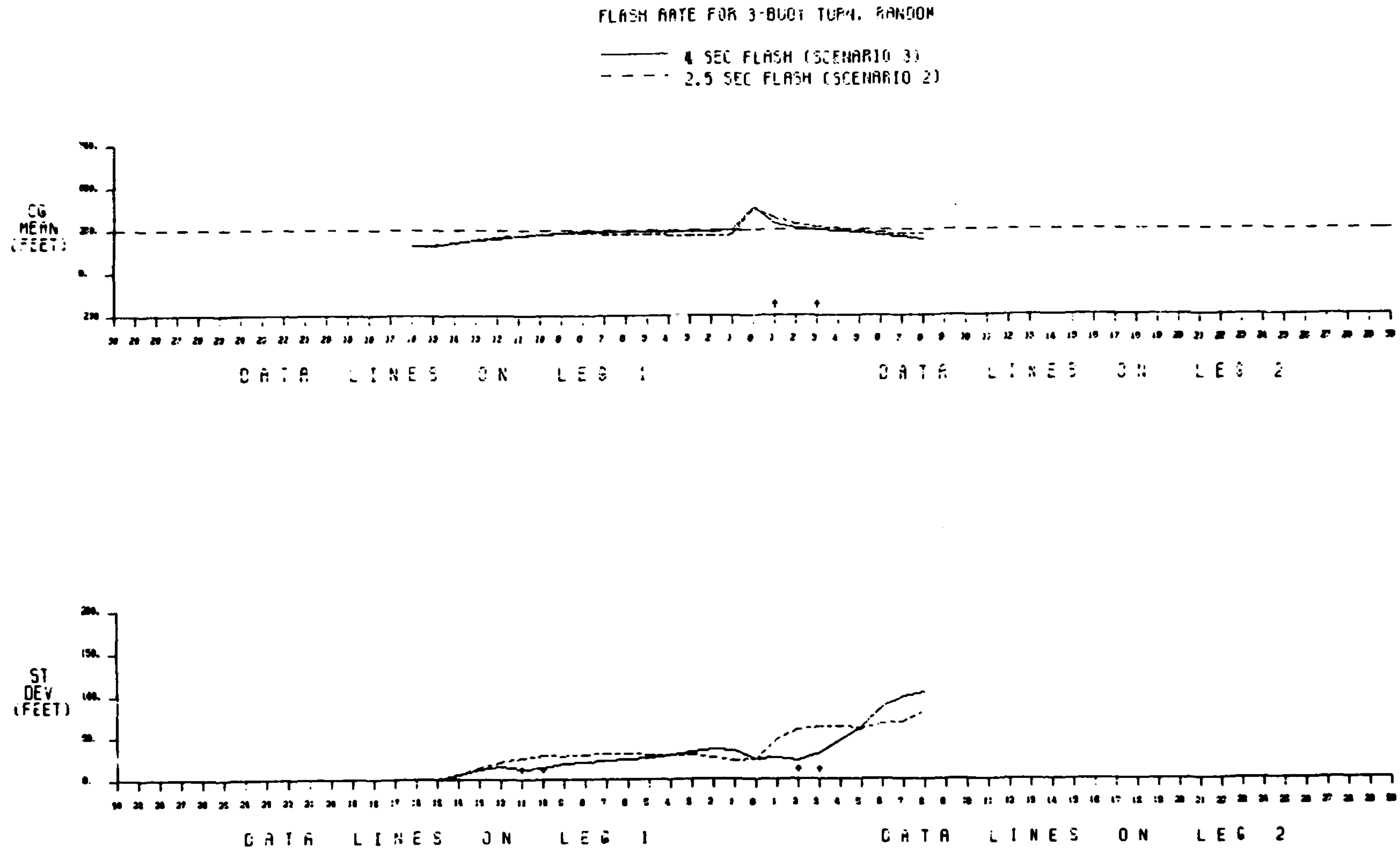


Figure 17B. Comparison Plot for Flash Rate in Three-Buoy Turn (4 sec. versus 2.5 sec.).

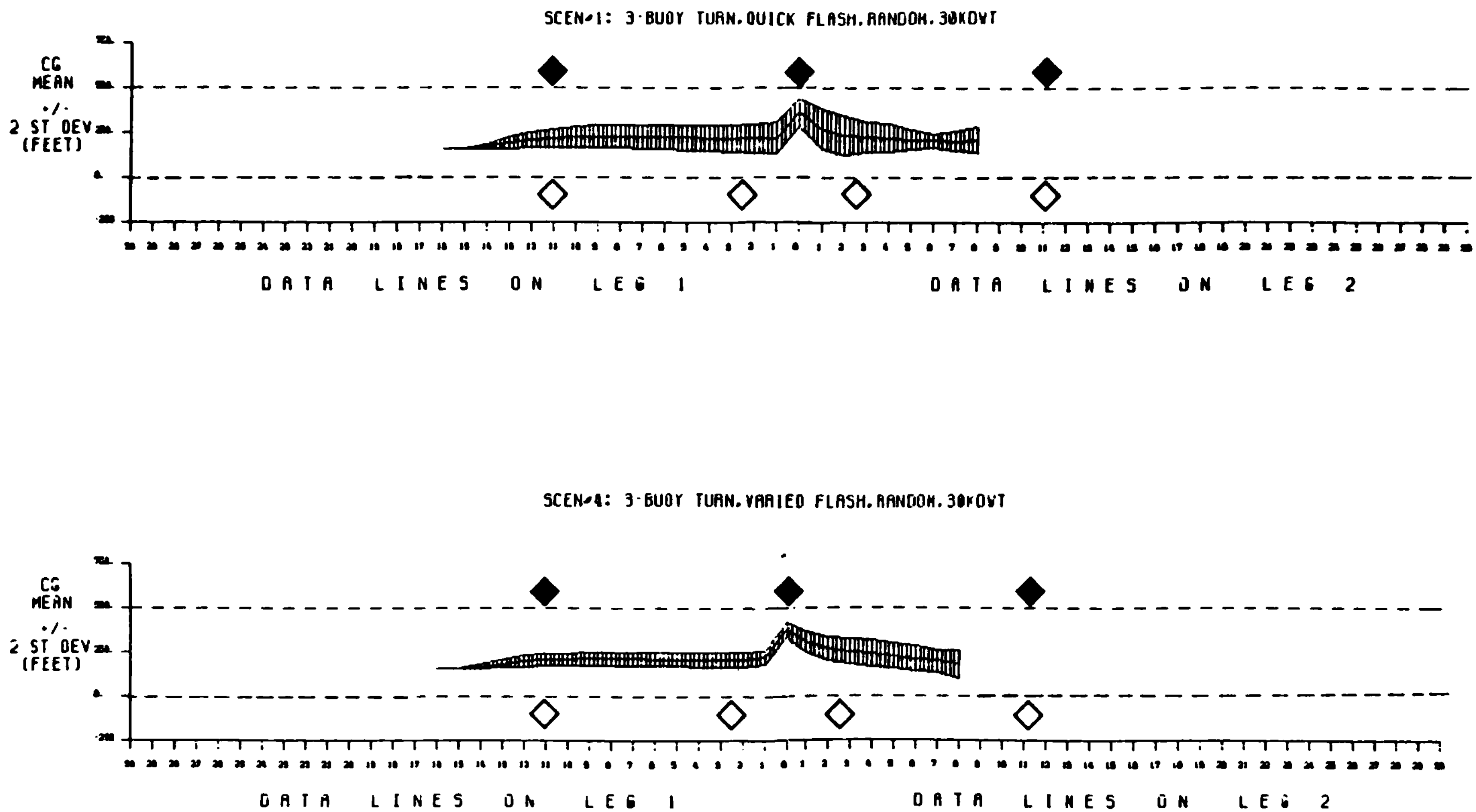


Figure 18A. Combined Plots for Number of Quick Flash in Three-Buoy Turn.

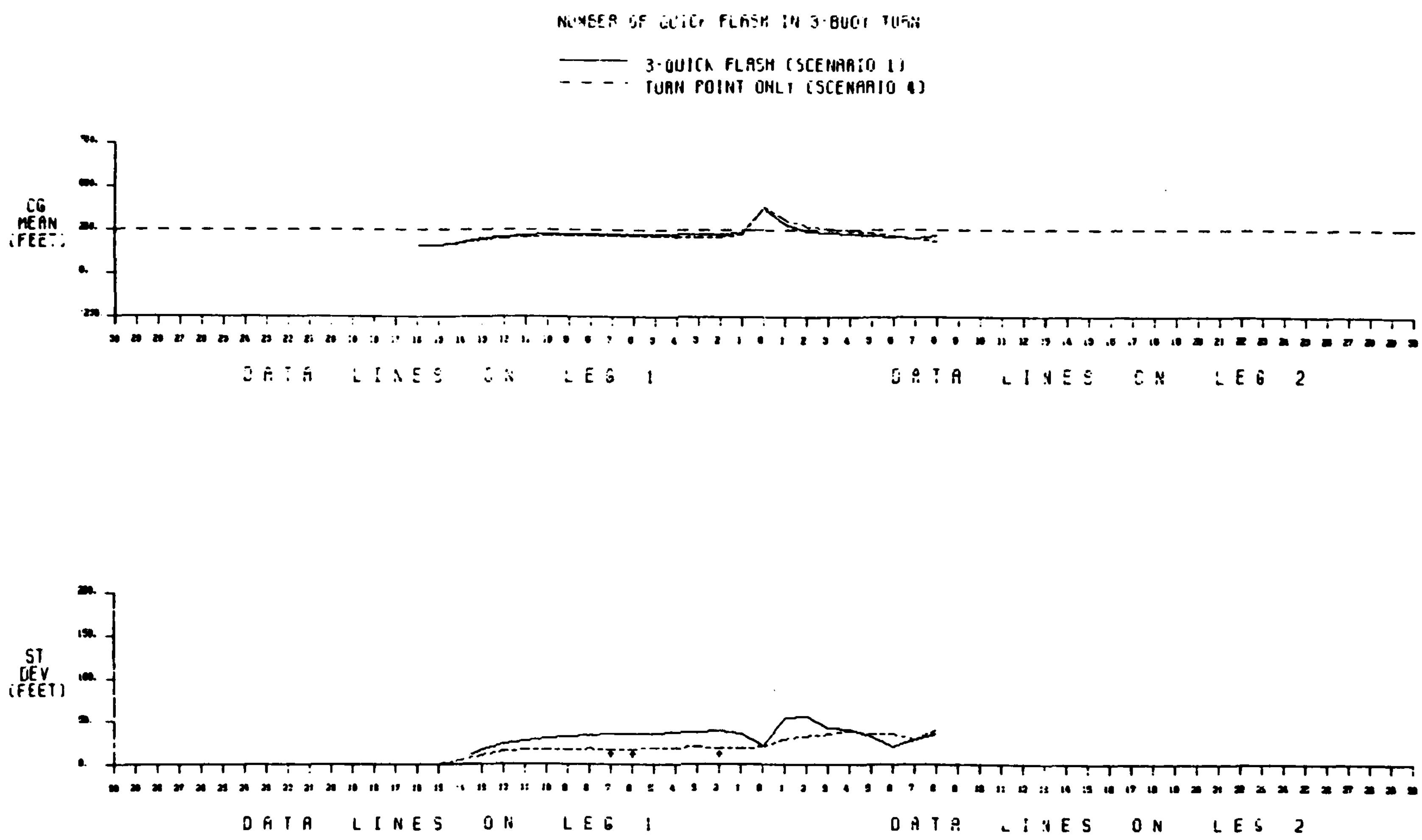


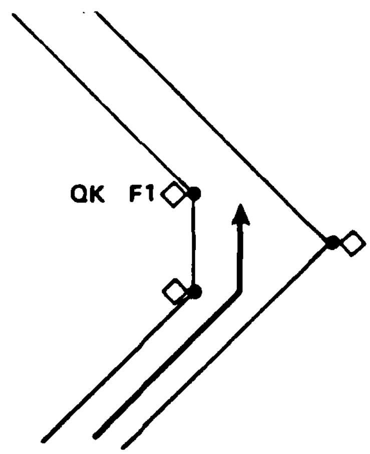
Figure 18B. Comparison Plot for Number of Quick Flash in Three-Buoy Turn.

critical at the turnpoint. The standard deviation is smaller for this group in the recovery region of the turn.

A different comparison Figure 19 between pooled scenarios containing quick flash at the turnpoint versus those scenarios that lack quick flash at the turnpoint leads to similar results. The most striking difference is the discrepancy between the standard deviations in Leg 2. Pooled Scenarios 1 and 4 show a considerably smaller standard deviation than Scenarios 2, 3, 5 and 6. This suggests that the group without the quick-flash buoy in the turnpoint has more difficulty in safely making the turn. The recommendation based on these results is to place a quick-flash buoy in the turnpoint.

The notion that pilots can perform adequately with only one quick-flash buoy located at the turnpoint implies that the pullout buoy need not be quick flash. It does not make sense, however, to conclude that performance is better with slower flash rates. It has already been shown in the previous section that the quick-flash condition exhibits performance most similar to daytime when compared to slower flash rates. A more reasonable interpretation is that the pullout buoy itself is less critical in aiding turning maneuvers and under some circumstances it may be reasonable to use slower flash rates. For example, research from the CAORF experiment and the Ship Variables experiment suggests that the pullout buoy may be less critical in situations where there is a lower angle turn (for example, 15 degrees) and for ships 30,000 dwt and smaller.

The effects of lighting characteristics in cutoff turns (those widened by dredging) were not evaluated in the present experiment; but it was discussed with the pilots. The relative ease of negotiating such turns was reflected in the lack of agreement among pilots as to how they would like to see them marked. If there was a consensus, it was consistent with the findings on noncutoff turns. The pilots would prefer to turn around a quick flash buoy.



This means that for two-way traffic both inside buoys should be lighted with quick flash. There was a minority opinion that two lights of the same color should not have the same characteristic, but performance in the noncutoff turn with three quick-flash lights suggests this would not be a problem. The manual recommends three buoys in a cutoff turn with a possibility that two-way traffic will pass in the turn. There seems to be no strong pilot preference for the light characteristics of this less critical buoy.

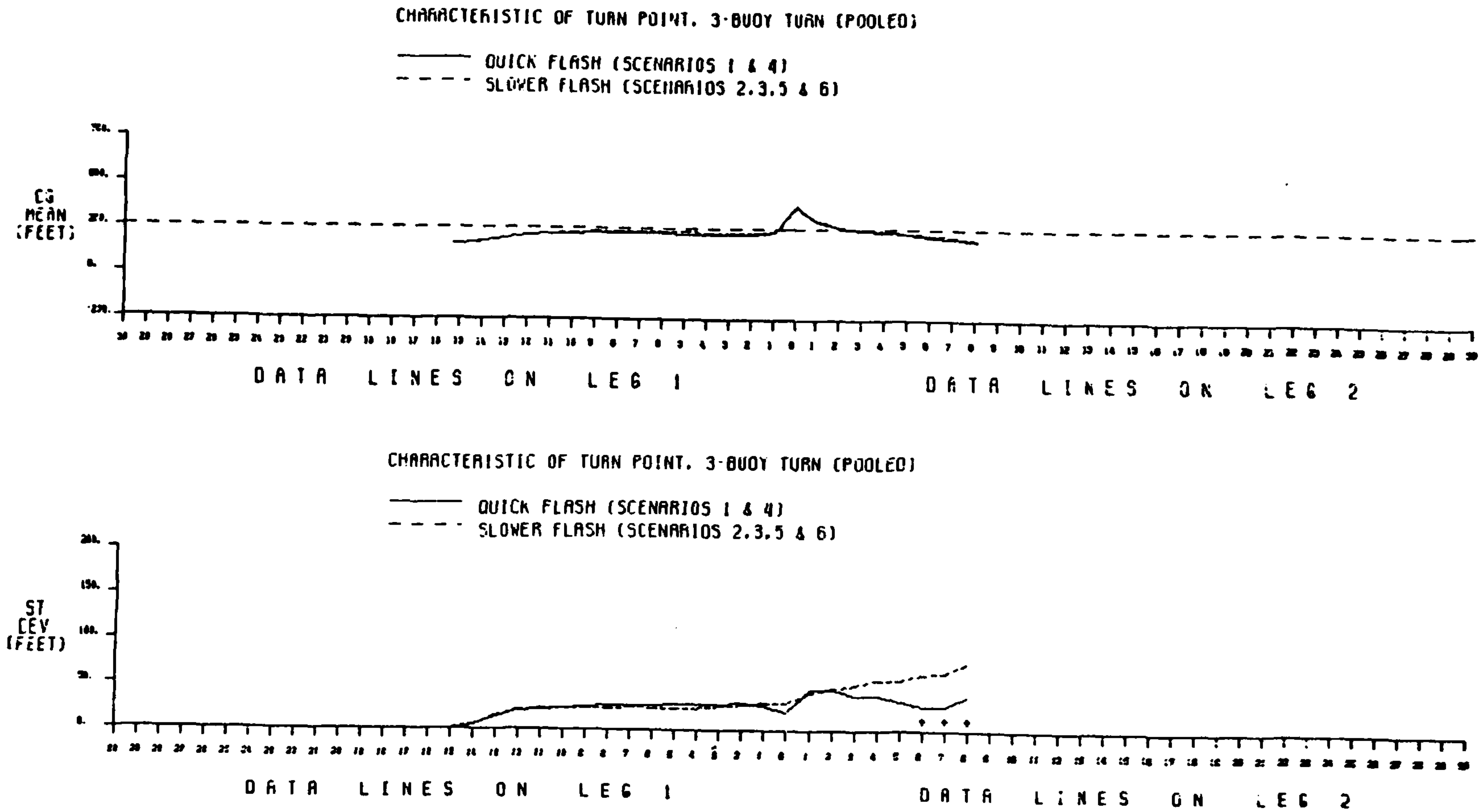


Figure 19. Comparison Plot of Characteristic of Turn Point, Three-Buoy Turn (Pooled).

3.4 THE EFFECT OF SYNCHRONIZATION ON PILOTING PERFORMANCE

Synchronization was compared at the two slower flash rates against randomly flashing buoys to assess its effectiveness in aiding piloting. The pilots described synchronization as helpful only in picking out the turn buoys. It was of no assistance in maneuvering through the turn. These comments are borne out by the data. In both the 2.5-second and 4-second comparison of synchronized versus random flash condition (Figures 20A, 20B, 21A, and 21B) there are no meaningful differences in Leg 2. There are significant differences in Leg 1, however, where they would be expected if synchronization helps pilots in identifying the turn buoys. The random versus synchronized comparison at the 2.5-second flash rate (Figures 20A and 20B) shows a smaller standard deviation for the synchronized condition. As the vessel approaches the turn, however, this smaller standard deviation increases becoming larger than the random condition by the time the ship is in the turn. Although the lights were helpful in picking out the buoys in the turn, they did not aid pilots in maneuvering through the turn. When close to the turn, the pilots cannot see more than one buoy at a time and the effects of synchrony breaks down.

The identitication effect of synchronization does not stand up across the 4-second condition. Figure 21A and 21B illustrates a finding opposite to that found in the 2.5-second condition. In this situation, performance in the 4-second random condition is statistically better than the synchronized condition. At the 4-second synchronized flash rate, a flash rate that is slow to begin with, the interval between the time the first light appears and then reappears may be long enough to interfere with identifying where the turn buoys are located. All the lights are off for the same period leaving no visual cues for the pilot to orient himself in the synchronized condition, whereas in the random condition, one of the three buoys may be flashing within any given 4-second interval.

These findings suggest that synchronization is effective only under a very limited set of circumstances. Although synchronization appears to help identification of the turn buoys using a 2.5-second flash, this effect is not strong. Synchronization appears to help identification of the turn buoys only with the 2.5 second flash rate and provides no help in the turn. If synchronization was implemented, these results imply that the breakdown of syncnronization due to mechanical failure would not result in unacceptable trackkeeping performance. Asynchronization of lighted buoys would result in performance equivalent to that of the random flash conditions, conditions under which pilots normally navigate.

3.5 QUICK FLASH VERSUS SYNCHRONIZATION

When compared to random quick flash, the pilots in the synchronized condition approach the turn with a statistically smaller standard deviation. However, pilots in both conditions perform adequately. Figures 22A and 22B displays this comparison. The important differences occur in the turn and leg 2. In the turn and throughout Leg 2 the standard deviation for the quick flash condition goes up to about 56 feet and then gradually decreases. The synchronized condition, on the other hand, increases through the turn and continues to increase gradually through Leg 2. So while

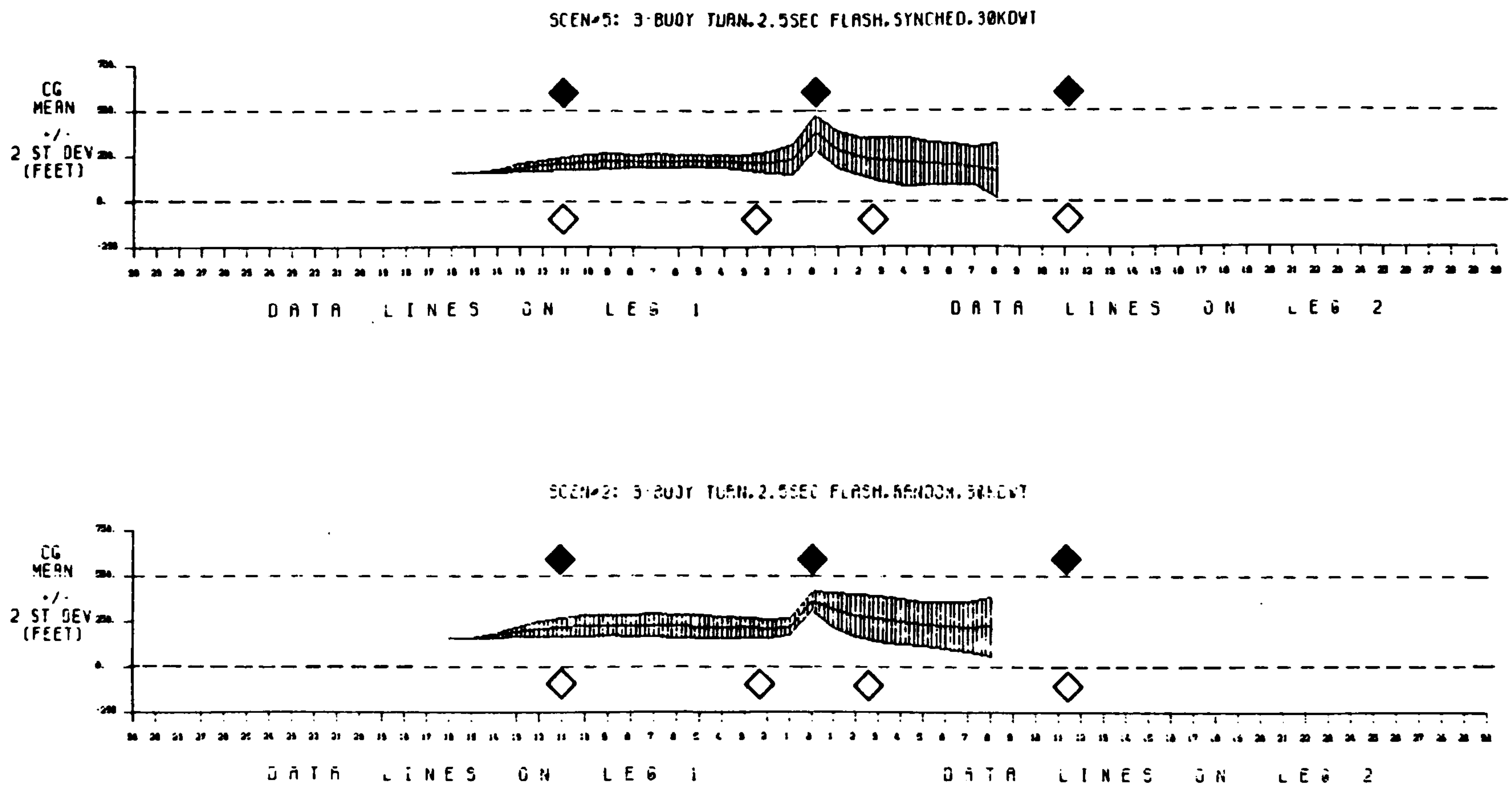


Figure 20A. Combined Plots for Synchrony, 2.5 sec. Flash.

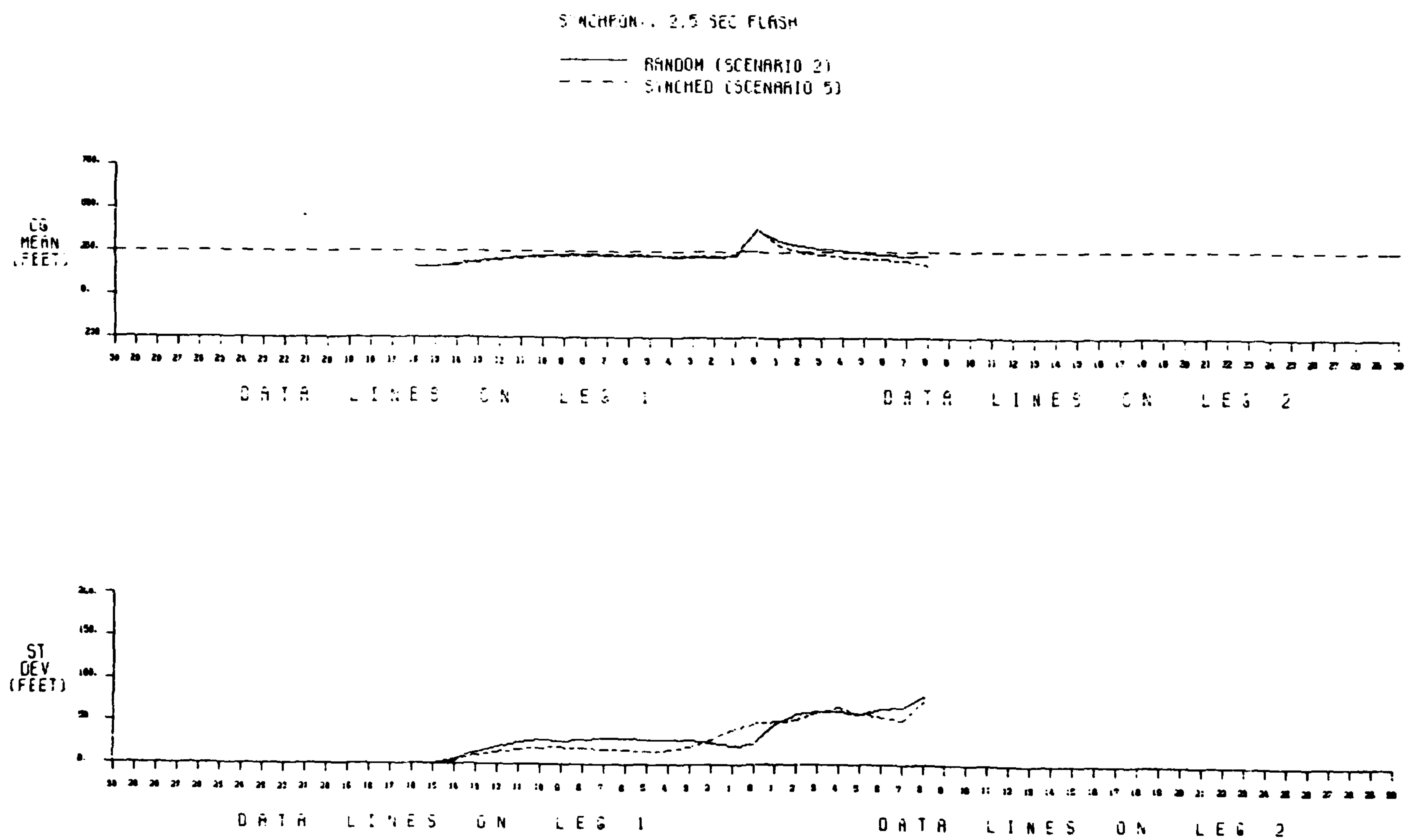


Figure 20B. Comparison Plot for Synchrony, 2.5 sec. Flash.

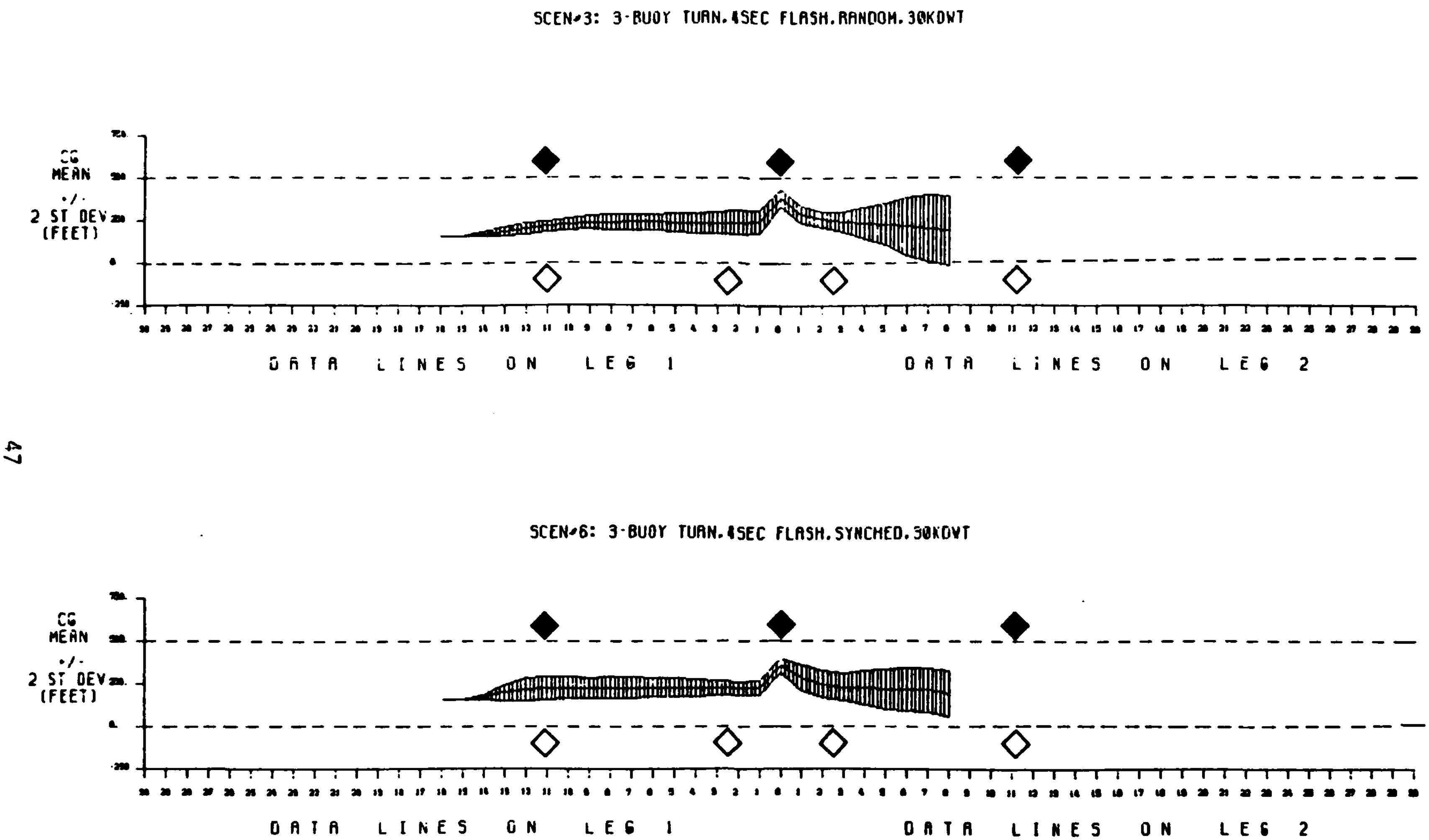


Figure 21A. Combined Plots for Synchrony, 4 sec. Flash.

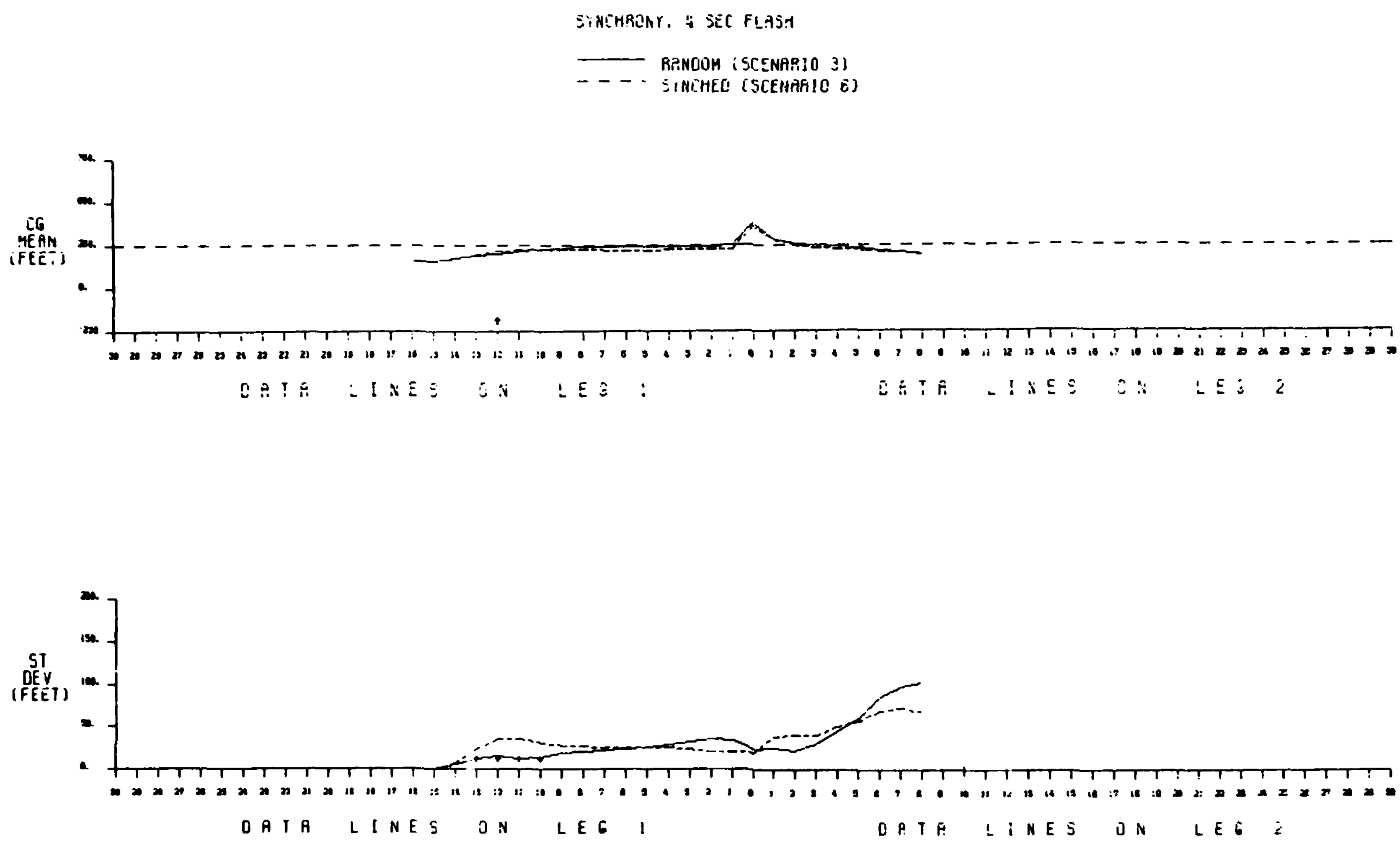


Figure 21B. Comparison Plot for Synchrony, 4 sec. Flash.

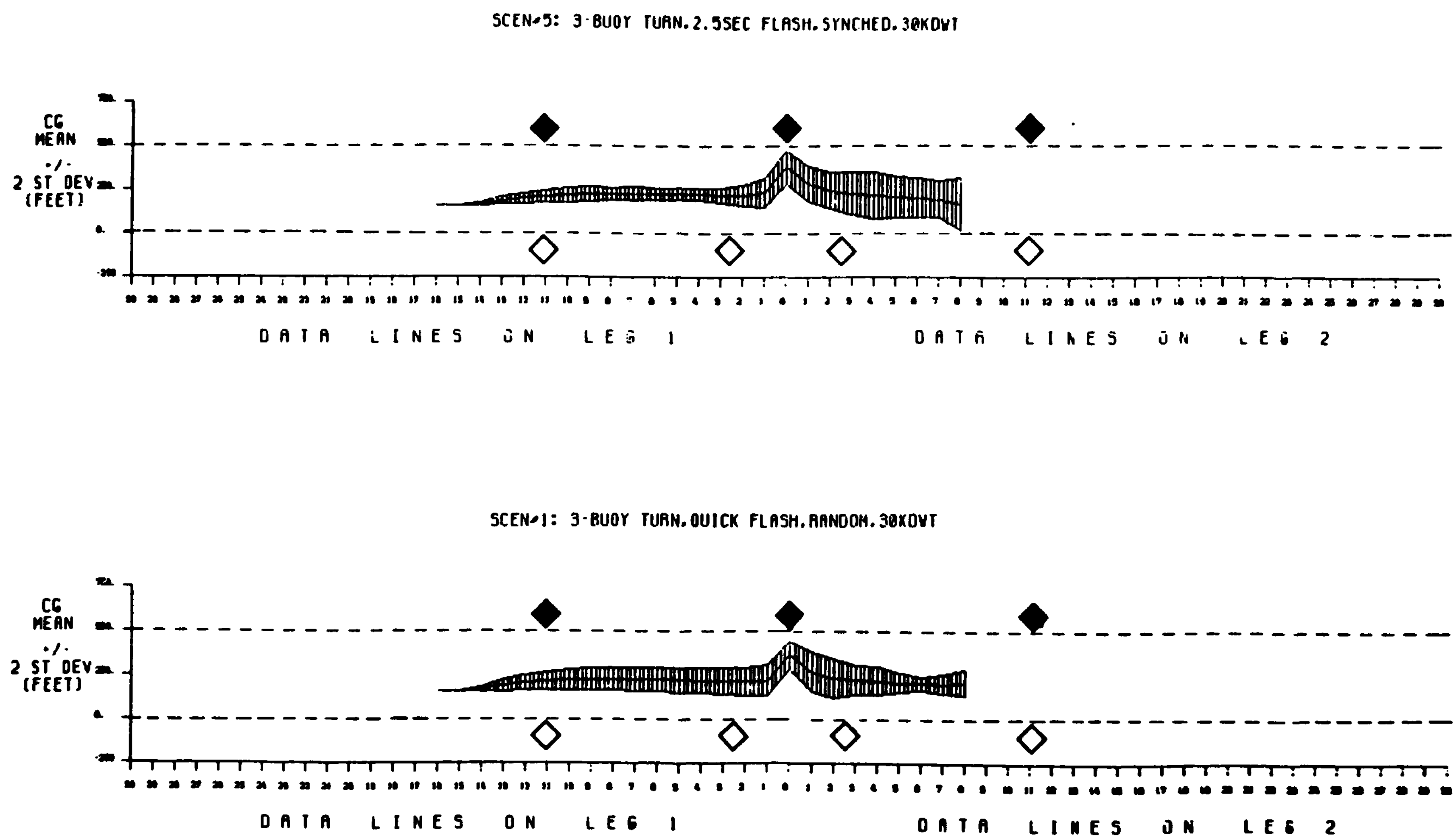


Figure 22A. Combined Plots for Quick Flash Versus Synchrony, Three-Buoy Turn.

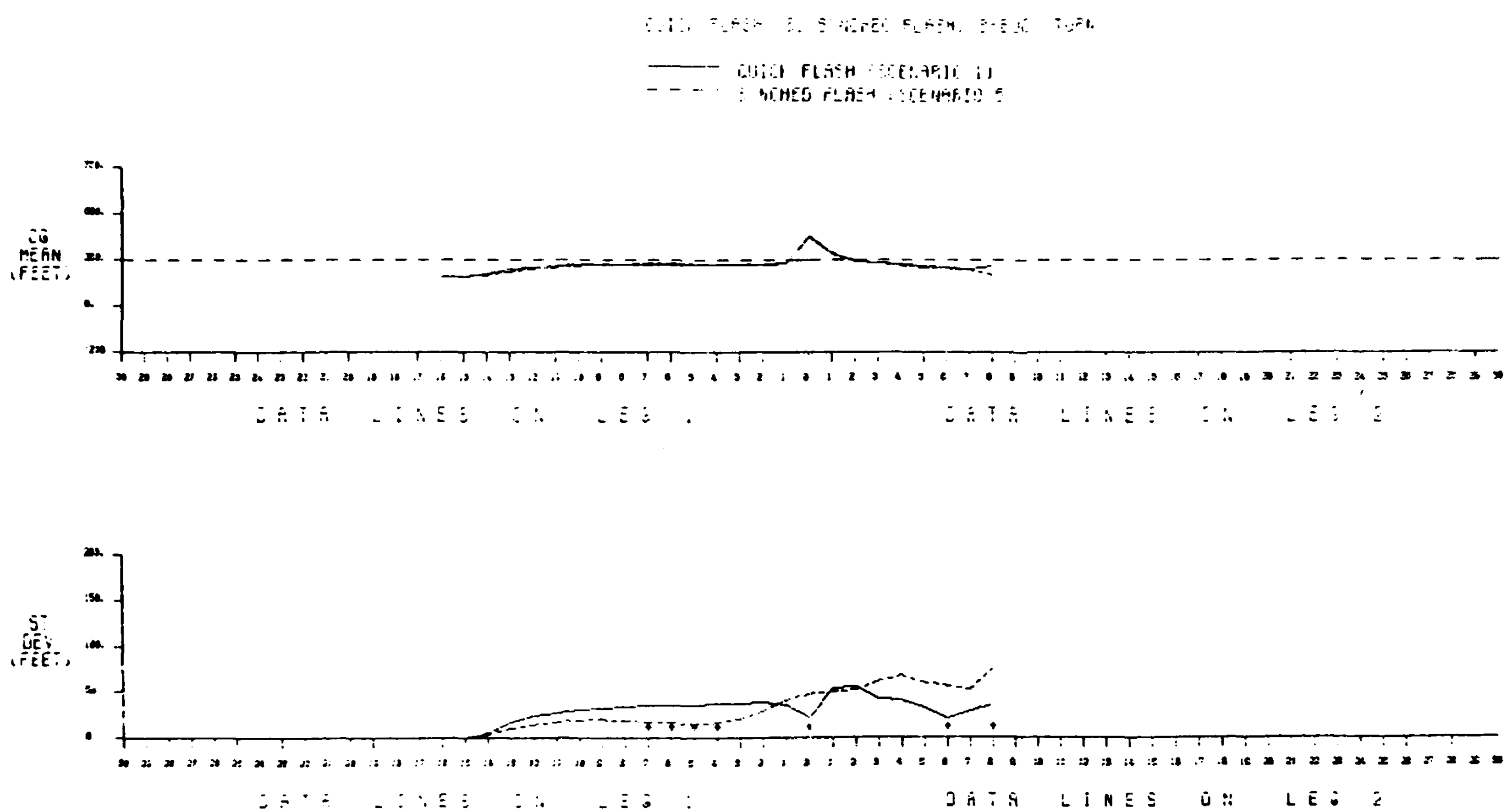


Figure 22B. Comparison Plot for Quick Flash Versus Synchrony, Three-Buoy Turn.

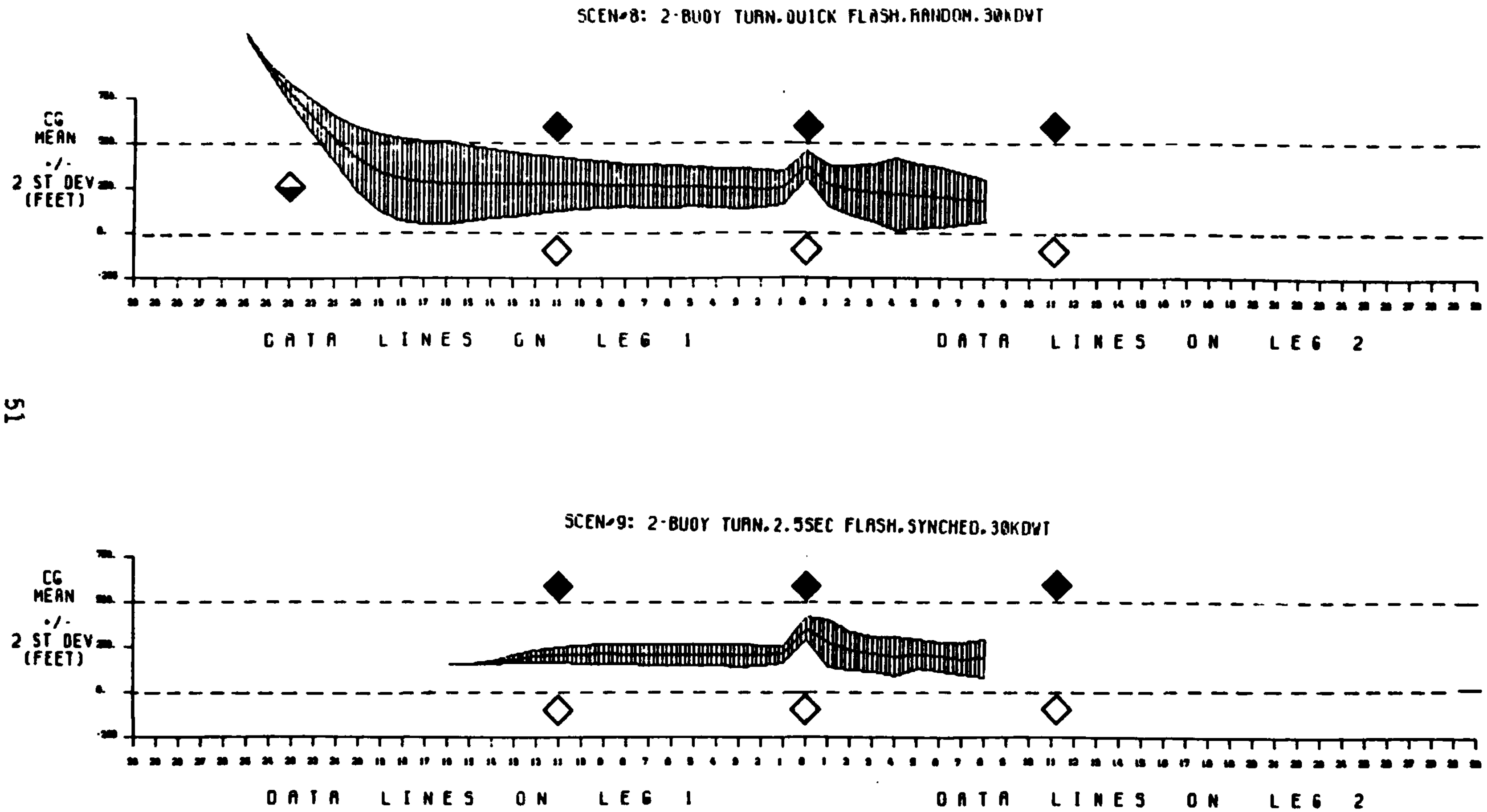


Figure 23A. Combined Plots for Quick Flash Versus Synchrony, Two-Buoy Turn.

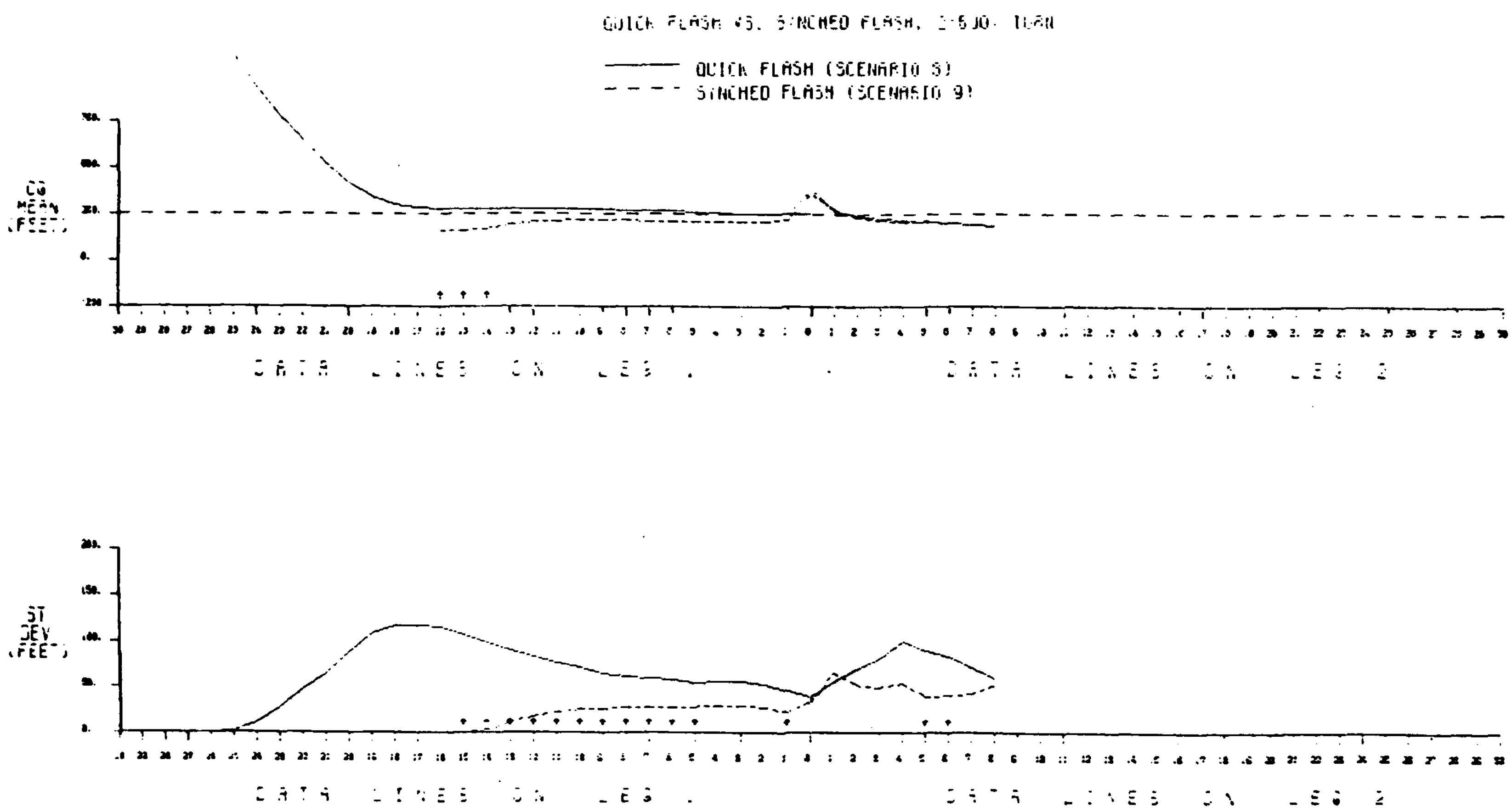


Figure 23B. Comparison Plot for Quick Flash Versus Synchrony, Two-Buoy Turn.

performance is comparable in both conditions, performance in the quick flash is superior to that in the synchronized condition through the turn.

The two-buoy comparison shown in Figures 23A and 23B is more difficult to interpret. The two-buoy condition is confounded by the fact that Scenario 8 begins in a different place from the other scenarios, beginning outside the channel. This scenario requires an initial maneuver using a 4-second flash as a navigational aid that makes it difficult to interpret the degree to which to maneuver through the turn of interest and the degree to which recovery in Leg 2 is due to factors of interest other than quick flash and synchronization. Because of successful maneuvers in the Ship Variables experiment, dissimilar performance was not expected in the Turn Lighting experiment. However, the nighttime condition was sufficiently more difficult so as to result in considerably poorer performance than in the Ship Variables experiment.

Although the synchronized condition shows better performance than quick flash in Leg 2 as indicated by a smaller standard deviation, it is highly unlikely that this result would occur in the real world. Assuming the more realistic conclusion that quick flash most closely approximates daytime performance it makes no sense that synchronized slow flash buoys should exhibit significantly smaller standard deviations. An explanation more consistent with the findings discussed thus far, attributes the smaller standard deviation in this comparison to the effects of the approach into the channel from which the pilots never completely recover. No definite conclusion is possible from the two-buoy comparison and any generalization must be based on findings in the three-buoy condition.

3.6 CONCLUSION

Synchrony seems to have little effectiveness in turn marking. The empirical findings confirm the pilots' comments that synchronization only helps in identifying the turn, but not in maneuvering through the turn. For the pilots who responded favorably, synchronization helped them to pick out the turn buoys. However, none of the pilots preferred synchronization over quick flash. Some pilots, in fact, disliked synchronization because the buoys were all alike making it difficult to differentiate the position of the turn buoys at a distance. Recommendations supported here for turn lighting have been paraphrased by one of the pilots in this experiment who said "Tell the Coast Guard to forget synchrony and give us one more lighted buoy for the money!"

This does not mean that synchronization has no useful purpose, however. Several pilots suggested other uses where synchronized lights would form a range (e.g., the inside edge of a cutoff or the turnpoint buoy and the next straight channel buoy beyond). The findings of this experiment make it unlikely that such arrangements would be more effective than quick flash. Another suggestion was that an edge of a straight leg be synchronized when a channel runs along a shore and cultural lights make it difficult to pick out the channel lights. Cultural lights are so idiosyncratic to a location that this is not a problem for generic research. A third option would use a synchronized lighting arrangement at the part or channel entrance so that incoming ships could more quickly distinguish and identify the appropriate

buoys marking the channel from possibly distracting shore lights and other nonsignificant visual cues.

3.7 SUMMARY OF RECOMMENDATIONS FOR TURN LIGHTING CHARACTERISTICS

The following points summarize the effects of turn lighting characteristics on piloting performance and the recommendations that follow from these findings:

- Buoys most closely approximate daytime effectiveness when lighted with quick flash.
- For noncutoff turns, it is essential that the turnpoint or inside apex buoy be quick flash.
- For noncutoff turns, it is recommended that other turn buoys besides the turnpoint be quick flash as well.
- Synchrony does not enhance the effectiveness of buoys making the turn.

SECTION 4

EFFECTS OF BUOY ARRANGEMENT AND SHIP SIZE

4.1 INTRODUCTION

Previous experiments performed as part of the Aids to Navigation project reported meaningful performance differences due to the type of buoy configuration. Two- and three-buoy arrangements were evaluated as part of this experiment's goals to clarify and predict shiphandling performance differences under nighttime conditions. Ship size is another important variable that has been shown to mediate piloting performance. As ship size increases, differences in piloting performance due to a particular experimental condition tend to become more noticeable. The present experiment investigated the sensitivity of performance differences to changes in ship size under nighttime conditions. Two ship sizes, a 30,000 dwt tanker and 80,000 dwt tanker, were compared.

4.2 ARRANGEMENT OF BUOYS IN THE TURN

Turn performance for the two-buoy and three-buoy arrangements is illustrated in Figure 24, with more precise performance for the three-buoy turn. Figures 25A and 25B show similiar means, but a significantly greater standard deviation for the two-buoy arrangement. These findings must be interpreted cautiously, however, since the two scenarios begin at different places and it is possible that in Scenario 8 the pilot never sufficiently recovered from the effects of the maneuver into the channel in Leg 1.

The three-buoy arrangement shows more precise performance in other situations. The daytime condition of the One-side Channel Marking experiment illustrated in Figure 26A and 26B and the nighttime conditions pooled over light characteristics illustrated in Figure 27 support the superiority of the three-buoy arrangement. Table 5 (in Section 2) presents the ship's mean and standard deviation where the crosstrack acceleration due to the turn effects is ended and the wind and current effects are dominant. In each comparison the mean for the two-buoy arrangement is taken at a later dataline: crosstrack acceleration continues longer, resulting in a mean further to the outside of the centerline. The corresponding standard deviation is larger. It should not be concluded from these findings that three-buoy turns are unequivocally superior to the two-buoy turns. While performance under the conditions of this experiment was more precise for three-buoy turns; the two-buoy turn was, in fact, well within the limits of the channel. Rather, it should be understood that as conditions for passage through a turn become more severe; three-buoy turns will tend to provide better information necessary for piloting than two-buoy turns and, consequently, will contribute to safer performance.

The idea that both three-buoy and two-buoy arrangements can play a positive role within the appropriate context is consistent with pilot opinions on three-buoy and two-buoy arrangements. Of the ten pilots in this experiment, four pilots preferred the three-buoy arrangement under all possible conditions, three pilots preferred the two-buoy arrangement under all possible conditions, and three pilots would choose either the two-buoy

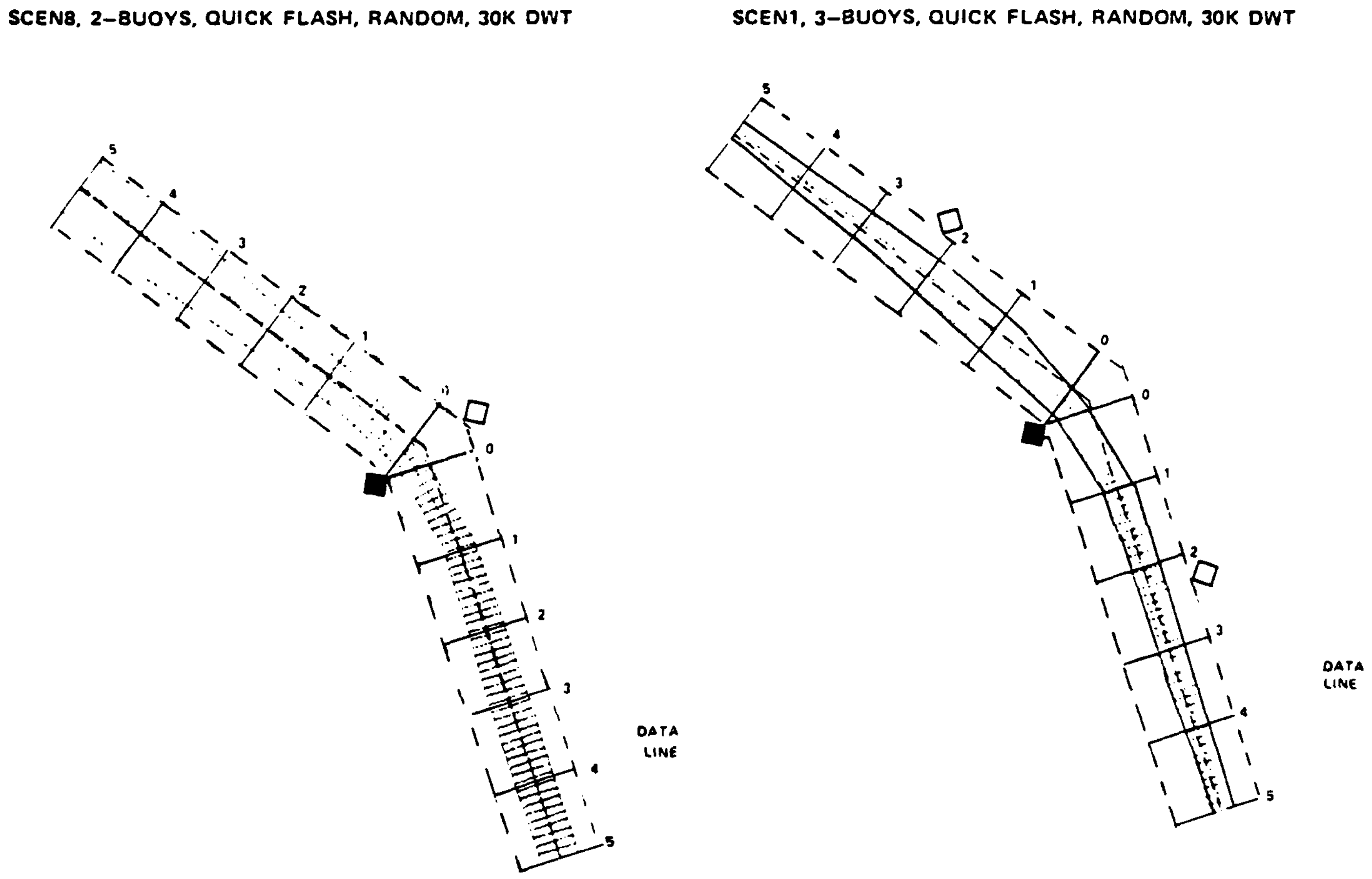
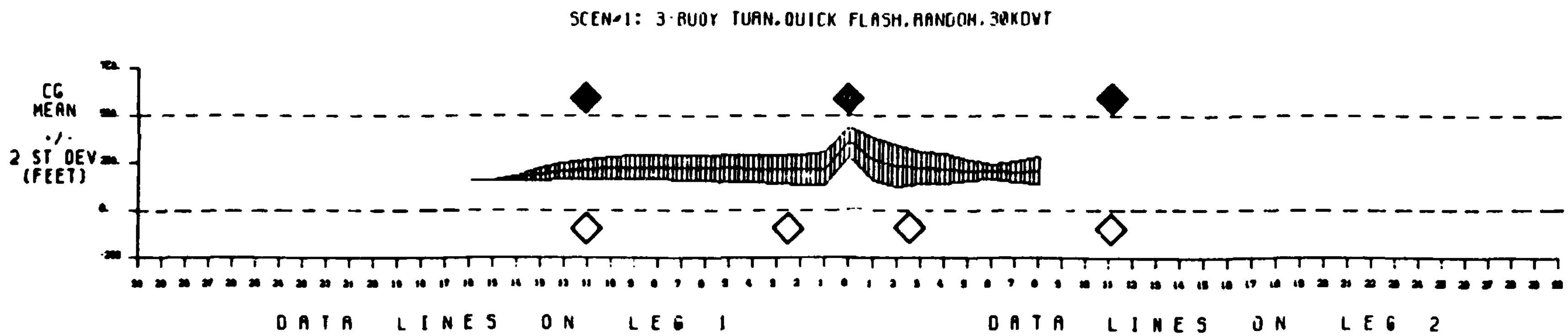


Figure 24. Turnplot Comparison of Three-Buoy and Two-Buoy Arrangement.



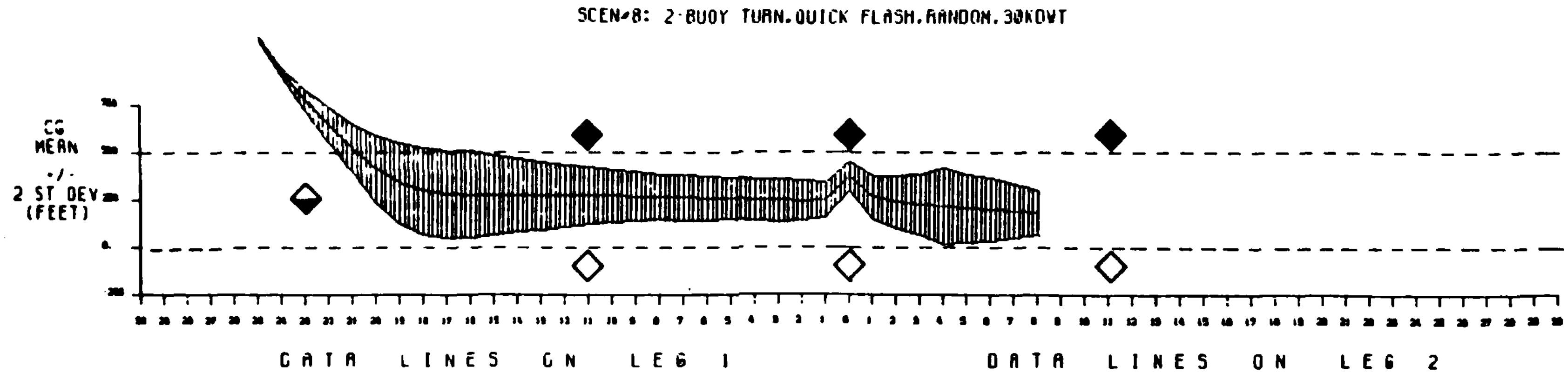


Figure 25A. Combined Plots of Buoy Arrangement in the Turn (Quick Flash) at Night.

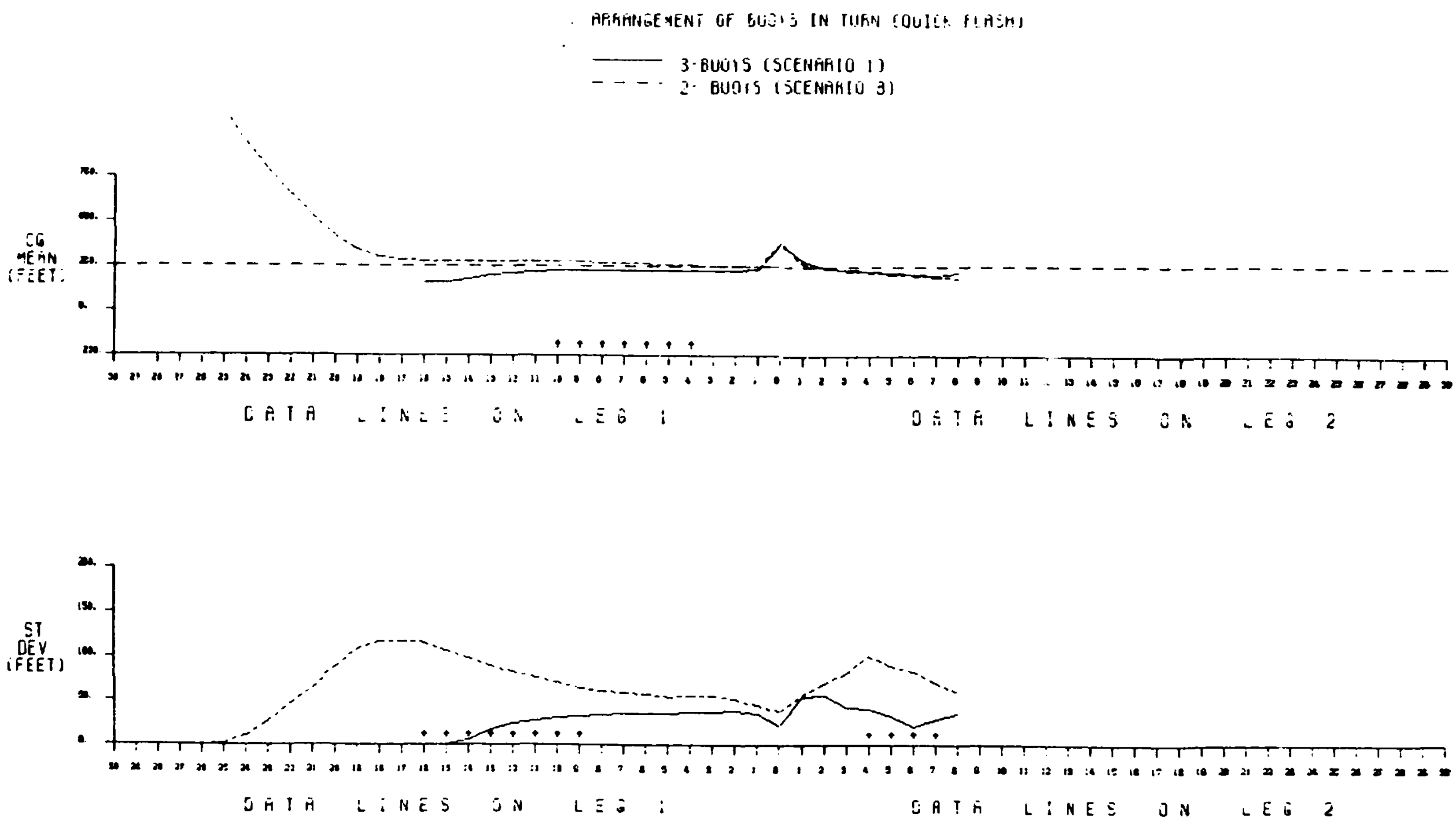


Figure 25B. Comparison Plot of Buoy Arrangement in the Turn (Quick Flash) at Night.

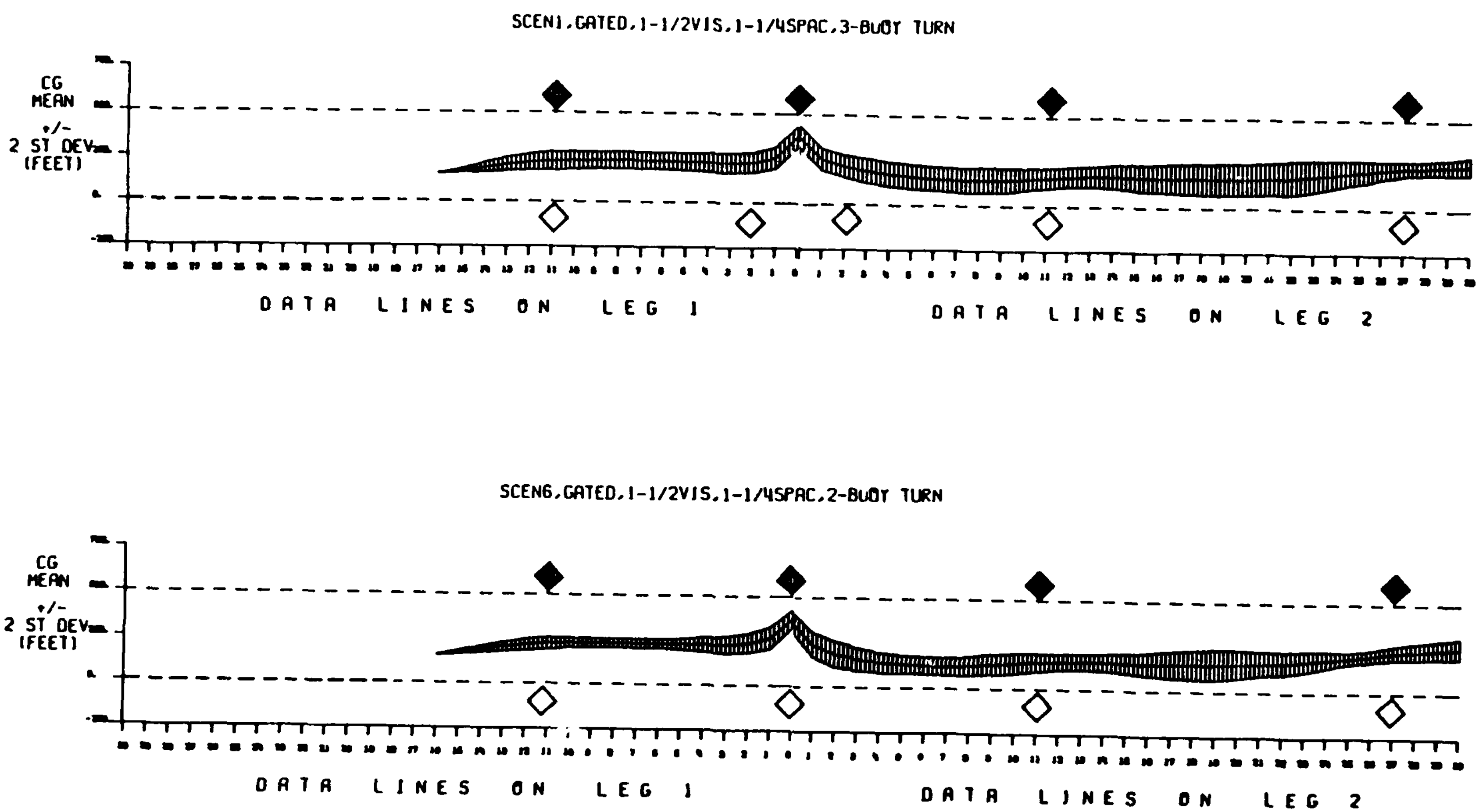


Figure 26A. Combined Plots of Buoy Arrangement in the Turn in Daylight.

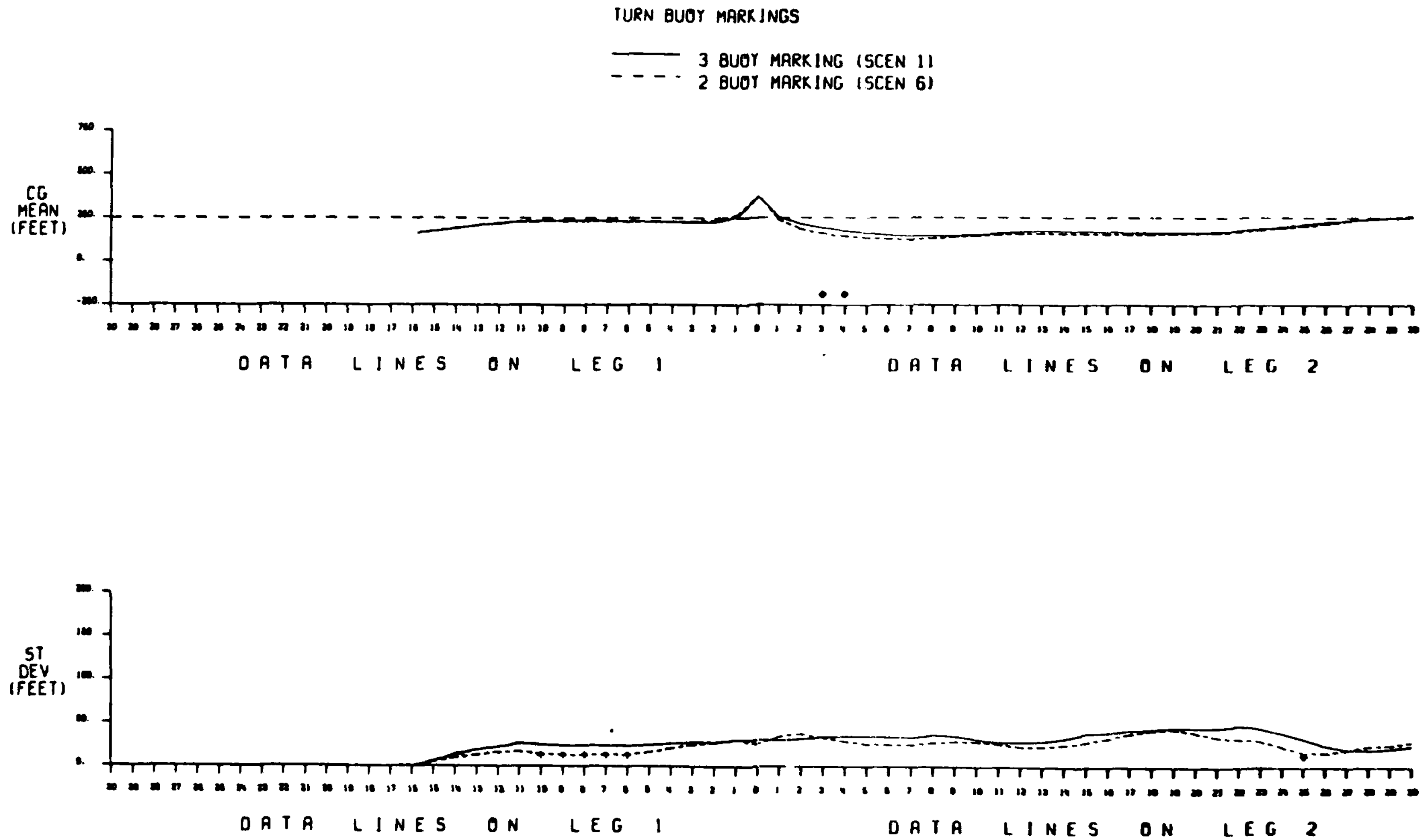


Figure 26B. Comparison Plot of Buoy Arrangement in the Turn in Daylight.

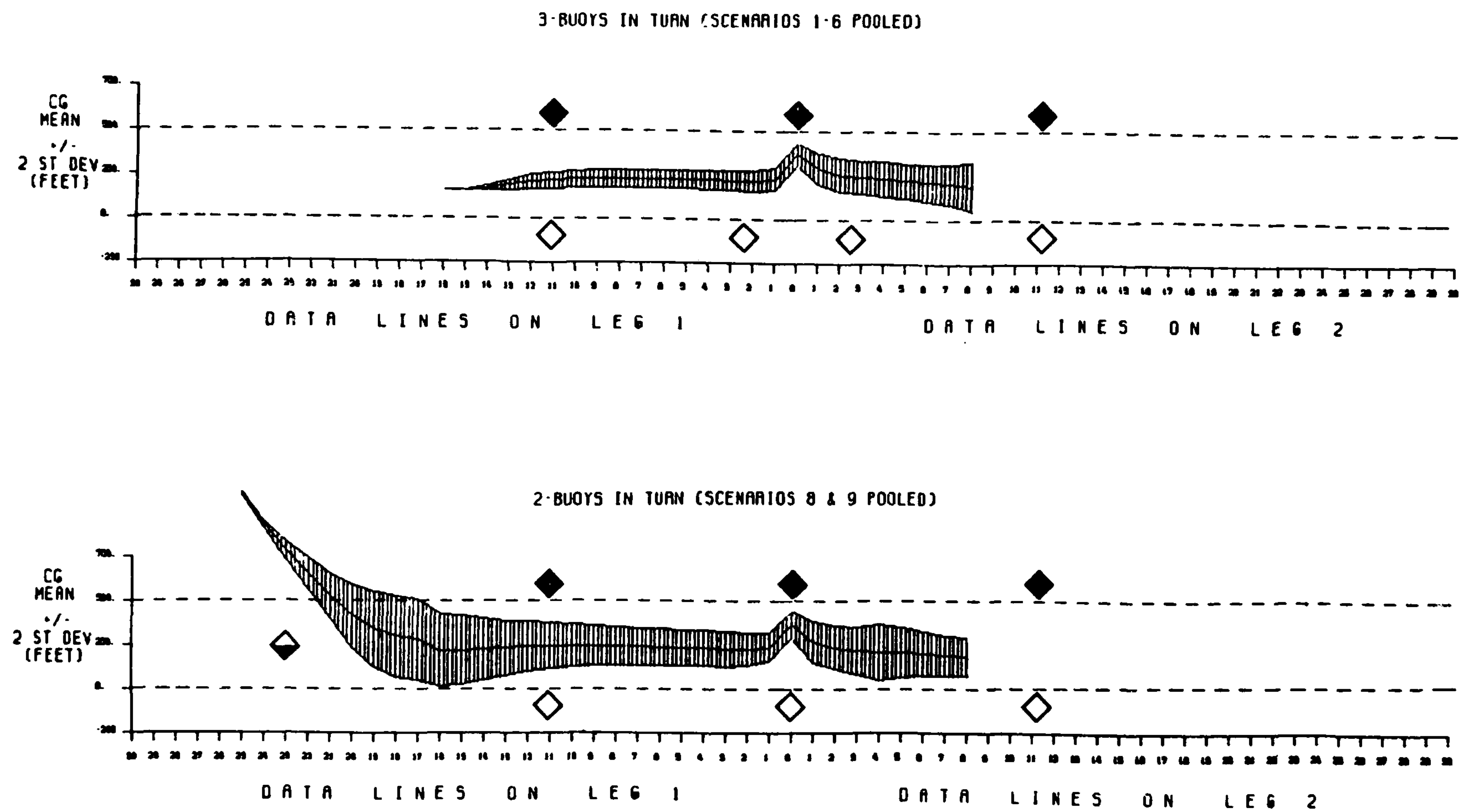


Figure 27. Combined Plots of Pooled Three-Buoy and Two-Buoy Arrangements.

or three-buoy arrangement depending upon the particular set of circumstances in which he was placed. The main reason cited by the pilots in favor of the three-buoy configuration was the greater certainty as to when to begin making the turn. This reason took on greater significance as ship size increased. The three-buoy condition also allowed better judgment of swing and where and when the vessel would come out of the turn. The bigger the angle of the turn, the more the three-buoy turn was preferred. By contrast, the two-buoy arrangement enabled the pilot to determine whether the buoys were on station. Some pilots prefer to go further into the turn before making rudder or course adjustments, a strategy that the two-buoy arrangements encourage. The following section provides support for the pilots who spoke of a relationship between buoy arrangement and ship size.

4.3 SHIP SIZE IN A TWO-BUOY TURN

Both Figures 28A and 28B, comparing 30,000 dwt and 80,000 dwt tankers, reveal significant performance differences in the crosstrack mean for ship size. In Leg 1, the 80,000 dwt tanker shows a mean that overshoots the centerline and a distribution partly outside the right channel edge. The crosstrack standard deviation is larger for the smaller ship. Since the smaller ship is more maneuverable and easier to control through the turn, this larger standard deviation must reflect a greater choice of track through the turn, rather than greater uncertainty about the location of the channel edge. The smaller standard deviation for the larger ship must reflect more limited options. Leg 2 shows similar performance differences to Leg 1. The larger ship overshoots the centerline with a distribution that would take some vessel transits out of the channel and the smaller ship exhibits a larger standard deviation.

It is evident from both Leg 1 and Leg 2 that the 80,000 dwt tanker is more difficult to control. Although all the pilots in this experiment hold unlimited weight class licenses, several of them had little actual experience with tankers approaching 80,000 dwt. Two pilots commented that in the identical real-life situation, they would use tugs to assist them through the turn.

Unlike the other nighttime scenarios, Scenario 10 is the only condition with a crosstrack mean that resembles the daytime strategy. With the larger ship, pilots are unable to compensate adequately for the uncertainty of where the outside channel edge is located. In this nighttime condition, where the ship is more difficult to maneuver, the pilot is more dependent upon navigational aids for guidance through the turn. This interpretation provides additional support for the conclusion stated in the Ship Variables experiment: as the shiphandling situation increases in difficulty, safe navigation through a turn becomes more dependent upon the characteristics of the navigational aids, such as number of aids, placement, and lighting.

4.4 RECOMMENDATIONS FOR THE DESIGN OF AID ARRANGEMENTS IN THE TURN

Several variables are described in the text as having been identified as critical to piloting performance in turns. These are day/night, ship size, and buoy arrangement. (This is not an exhaustive list.) This section is a compilation of these conditions as they have been evaluated over several

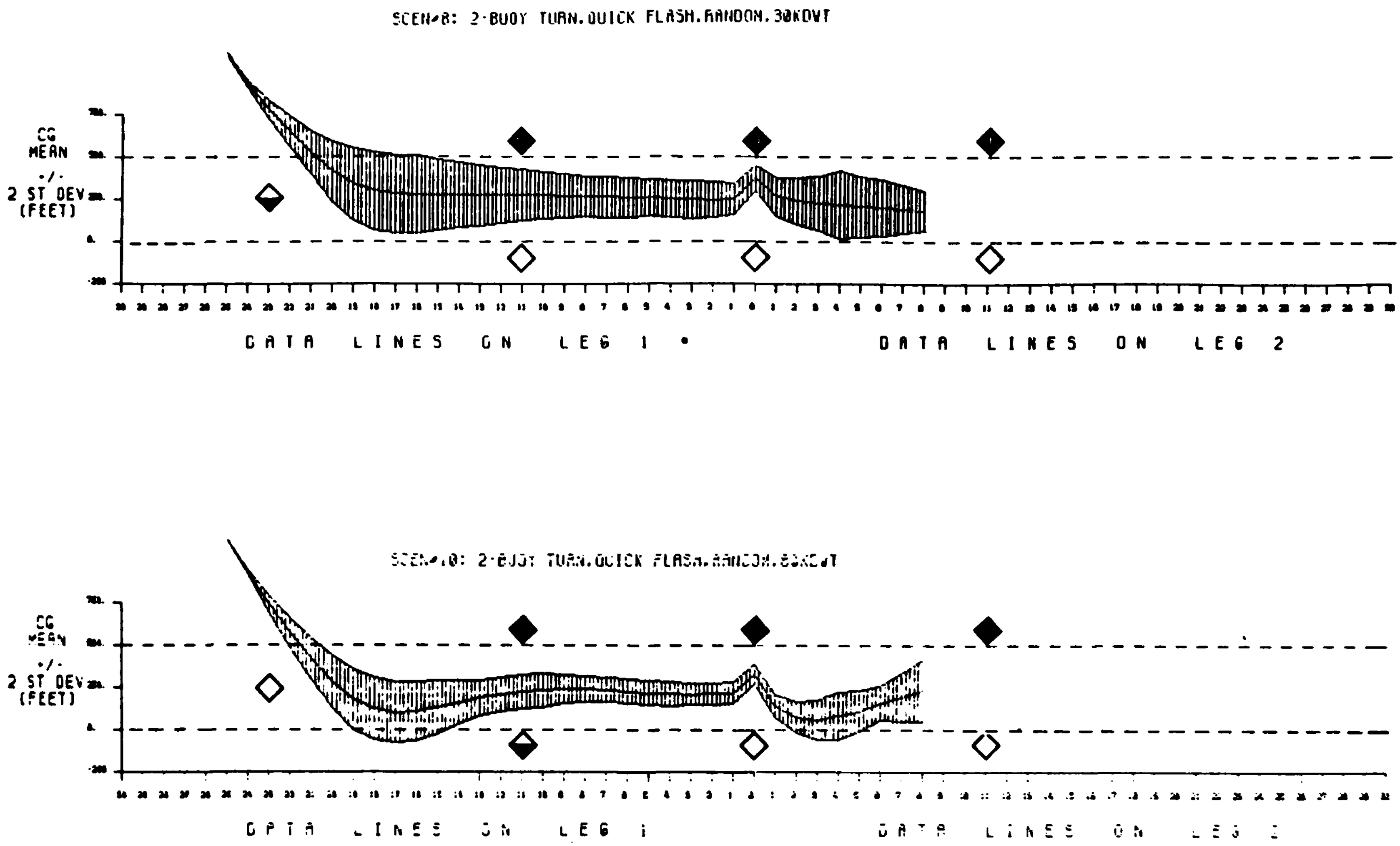


Figure 28A. Combined Plots Comparison of Ship Size in a Two-Buoy Turn.

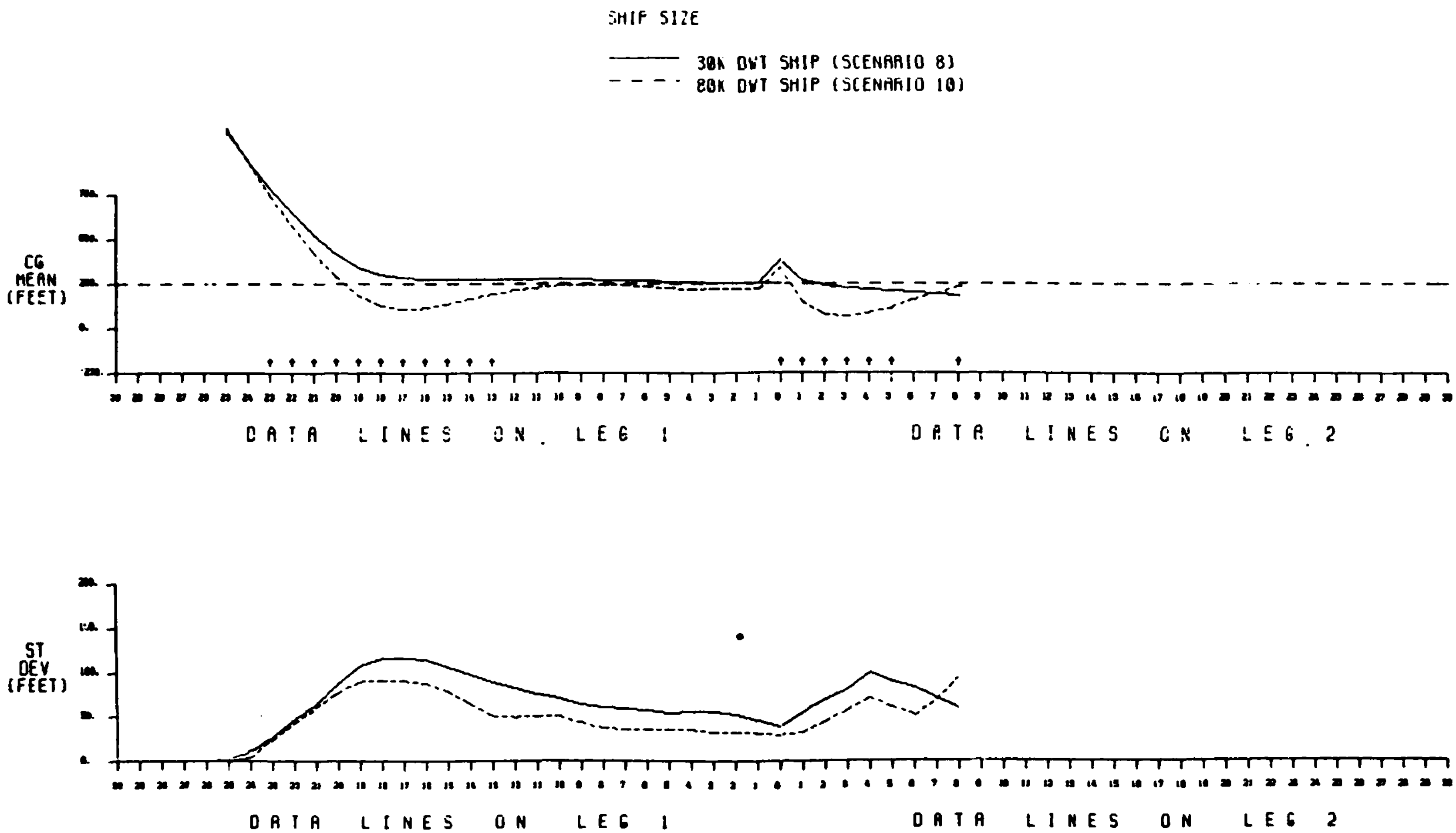


Figure 28B. Comparison Plot of Ship Size in a Two-Buoy Turn.

experiments, along with recommendations for the selection of aid arrangements. As was the case in the draft SRA manual, the organizing assumption is that such conditions as day/night and ship size constitute a problem and that aid arrangements constitute the solution to the problem. As a summary of the following discussion: severe conditions require maximum marking; less severe conditions allow more options.

The conditions available for consideration are presented in Tables 6 and 7. Ship size is represented by the 30,000 and the 80,000 dwt ship. Day and night turn performance is available for both ships. Performance for three-, twoand one-buoy arrangements is presented as available. In keeping with the recommendations in Section 3, night is represented by the quick-flash condition for the three-buoy arrangement. Because of difficulties with the two-buoy quick-flash condition described in Section 4.2, the data for the pooled two-buoy arrangement is included. In Table 6 performance is described quantitatively, using the mean and the standard deviation of the distribution of transits for each condition, and using the relative risk factor (RRF). As an operational definition of this index, a sample calculation for the first cell of the table is presented as Figure 29.

The relative risk factor (RRF) is the probability that for a given condition (ship size, day/night, etc,) and for given aid arrangements (three, two, or one buoys in the turn), there will be a "grounding." Because this probability is calculated using a mean and standard deviation from a simulator experiment, there are certain limitations to its use. The RRF is discussed more fully in the draft SRA manual and in the Validation Presimulation report.[14] For the present purposes, it is a way of comparing conditions that take both the mean and the standard deviation into account.

Comparison of the four quarters of Table 6 shows that ship size is a variable of overwhelming magnitude. With the 80,000 dwt ship it is not feasible to consider less than the maximum three-buoy turn arrangement. The day/night difference for the bigger ship suggests that it is worthwhile to recommend that it wait for daylight to transit a 500-foot channel with a 35-degree turn. For the 30,000 dwt tanker it is feasible to consider less than the maximum turn arrangement. How much less? Notice that there is no overlap between the values for the larger and the smaller ship. This suggests that if the larger ship is served by three buoys, the smaller ship is equally well served by the other alternatives. There is no value for the small ship at night in a one-buoy turn. Daytime performance suggests that the big change is between three and two buoys, not between two and one; therefore, it is unlikely that the smaller ship would reach the range of the larger, even with one buoy at night.

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[14]G.E. Grant and M.W. Smith. "Aids to Navigation Presimulation Report for Validation: Validation for a Simulator-Based Design Project." Technical Memorandum, U.S. Coast Guard, Washington, D.C., September 1982.

FORM XXX

CALCULATION OF RRF: TURN REGION

TURN IDENTIFICATION

1. TURN NAME AND LOCATION	2 CHART NO
3 LATITUDE AND LONGITUDE OF TURN APEX	

CHANNEL AND ENVIRONMENTAL PARAMETERS

4 ENTER CHANNEL WIDTH (FEET)	W= 500 FT
5. ENTER MAXIMUM CROSS CURRENT COMPONENT (KNOTS)	VX= .5 KTS
6. ENTER MAXIMUM WIND VELOCITY (KNOTS)	VW= KTS

DESIGN VESSEL PARAMETERS

7. ENTER SHIP TYPE AND DWT	30,000 DWT
8. ENTER MINIMUM EXPECTED TRANSIT SPEED (KNOTS)	VMIN = 6 KTS
9. ENTER MAXIMUM EXPECTED TRANSIT SPEED (KNOTS)	VMAX= KTS
10. ENTER SHIPS LENGTH (FEET)	L= 595 FT
11. ENTER SHIPS BEAM (FEET)	B= 84 FT

SRA DESIGN PARAMETERS (CIRCLE ONE)

12 AN DETECTION DISTANCE	LESS THAN 1 NM (RADAR)	GREATER THAN 1 NM (VISUAL)	
13. DAYLIGHT CONDITIONS	DAY	NIGHT, DUSK OR DAWN	
14. TURN CONFIGURATIONS	NONCUTOFF	CUTOFF	
15. SRA CONFIGURATIONS	3 BUOYS HI SENS RNG	2 BUOYS LO SENS RNG.	1 BUOY
16. TURN ANGLE	0 TO 20°	20 TO 40°	GREATER THAN 40 DEG

RADIO AID DESIGN PARAMETERS (CIRCLE ONE)

17 GYRO AIDING	YES	NO	
18 RMS NOISE AT SITE	0 TO 6 M	6 TO 18 M	18 TO 36 M
19 DISPLAY FORMAT	GRAPHIC W/PREDICTOR / PERSPECTIVE	GRAPHIC W/VECTOR / DIGITAL W/DISTANCE	DIGITAL W/TURNING
20 THROUGH SYSTEM RISE TIME	3 SEC	12 SEC.	24 SEC.

CALCULATE ADJUSTED MN AND SD

21A ENTER BASELINE MEAN TABLE C2,C3,C4 MN	22A ENTER MEAN SHIP CORRECTION FACTOR TABLE C5 MCSHP	23A ENTER MEAN SPEED CORRECTION FACTOR TABLE C6 MCSPD	24A ENTER MEAN WIDTH CORRECTION FACTOR TABLE __ MCWID		25 CALCULATE ADJUSTED MEAN MN'
(37 FT)x(	1)x(	1)x(	1)	=	(37 FT)

21B ENTER BASELINE STD DEV 1 TABLE C2,C3,C4 SD	22B ENTER S.D. SHIP CORRECTION FACTOR TABLE C5 SCSHP	23 B ENTER SD SPEED CORRECTION FACTOR TABLE C6 SCSPD	24B ENTER SD WIDTH CORRECTION FACTOR TABLE C7 SCWID		26 CALCULATE ADJUSTED STD DEV SD'
(32 FT)x(	1)x(	1)x(	1)	=	(32 FT)

CALCULATE ADJUSTED BEAM

27 ENTER SHIP LENGTH LINE 10 L	18 ENTER CROSS TRACK CURRENT VELOCITY LINE 5 VX	29 ENTER MINIMUM EXPECTED SPEED LINE 8 VMIN		30 ENTER SHIPS BEAM LINE 11 B		31 CALCULATE ADJUSTED BEAM B'
(595 /2)x(	.5 /	6)	+	(84 /2)	=	(66.79FT)

CALCULATE THE RELATIVE RISK FACTOR

32A ENTER CHAN. WIDTH LINE 4 W	33A ENTER ADJUSTED MEAN LINE 25 MN'	34A ENTER ADJUSTED BEAM LINE 31 B'		35A ENTER ADJUSTED STD. DEV LINE 26 SD'		36 CALCULATE STD. MULTIPLE TO STARBOARD NS
(500 /2)-(	37)-(	66.79)	/	(32)	=	(4.57)

32B ENTER CHAN. WIDTH LINE 4 W	33B ENTER ADJUSTED MEAN LINE 25 MN'	34B ENTER CHAN. ADJUSTED BEAM LINE 31 B'		35B ENTER ADJUSTED STD DEV LINE 26 SD'		37 CALCULATE SD STD MULTIPLE TO PORT NP
(500 /2)+(	37)-(	66.79)	/	(32)	=	(6.88)

38 DETERMINE PROB OF CROSSING NS TABLE C1 PS	39 DETERMINE PROB OF CROSSING NP TABLE C1 PP		40 CALCULATE RELATIVE RISK FACTOR RRF
(.0000)+(	.0000)	=	(.0000)

Figure 29. Sample Calculation of Relative Risk Factor.

TABLE 6. PERFORMANCE IN NONCUTOFF TURNS (QUANTITATIVE).

	Day						Night					
	Experiment	Scenario	Data Line	Mean	Standard Deviation	Relative Risk Factor	Experiment	Scenario	Data Line	Mean	Standard Deviation	Relative Risk Factor
30,000 dwt ship												
Three buoys	One-Side	1	2	37R	32	0.0000	Turn Light	1	2	8R	56	0.0012
Two buoys	One-Side	6	3	94R	33	0.0035	Turn Light	8,9	3	28R	67	0.0110
One buoy	Ship Variables	2	3	72R	45	0.0068						
80,000 dwt ship												
Three buoys	Ship Variables	7	2	112R	50	0.1922						
Two buoys							Turn Light	10	3	187R	58	0.7019
One buoy	Ship Variables	6	2	124R	69	0.3228						

The same conditions just considered are presented again in Table 7 with performance characterized by a qualitative label. The label is based on quantitative data, on track plots as described in Section 1.9.2 and used throughout this report. It is based on the placement (mean) and width(standard deviation) of the envelope of transits within the boundaries of the channel. Comparisons were made by inspection and by statistical tests. (This is the same method used for Section 8 of the draft manual.) The cases were sorted into the following groupings:

- optimal, the most precise piloting in the series
- acceptable, noticeably worse than optimal, but still within the boundaries of the channel
- unacceptable, not entirely contained within the boundaries

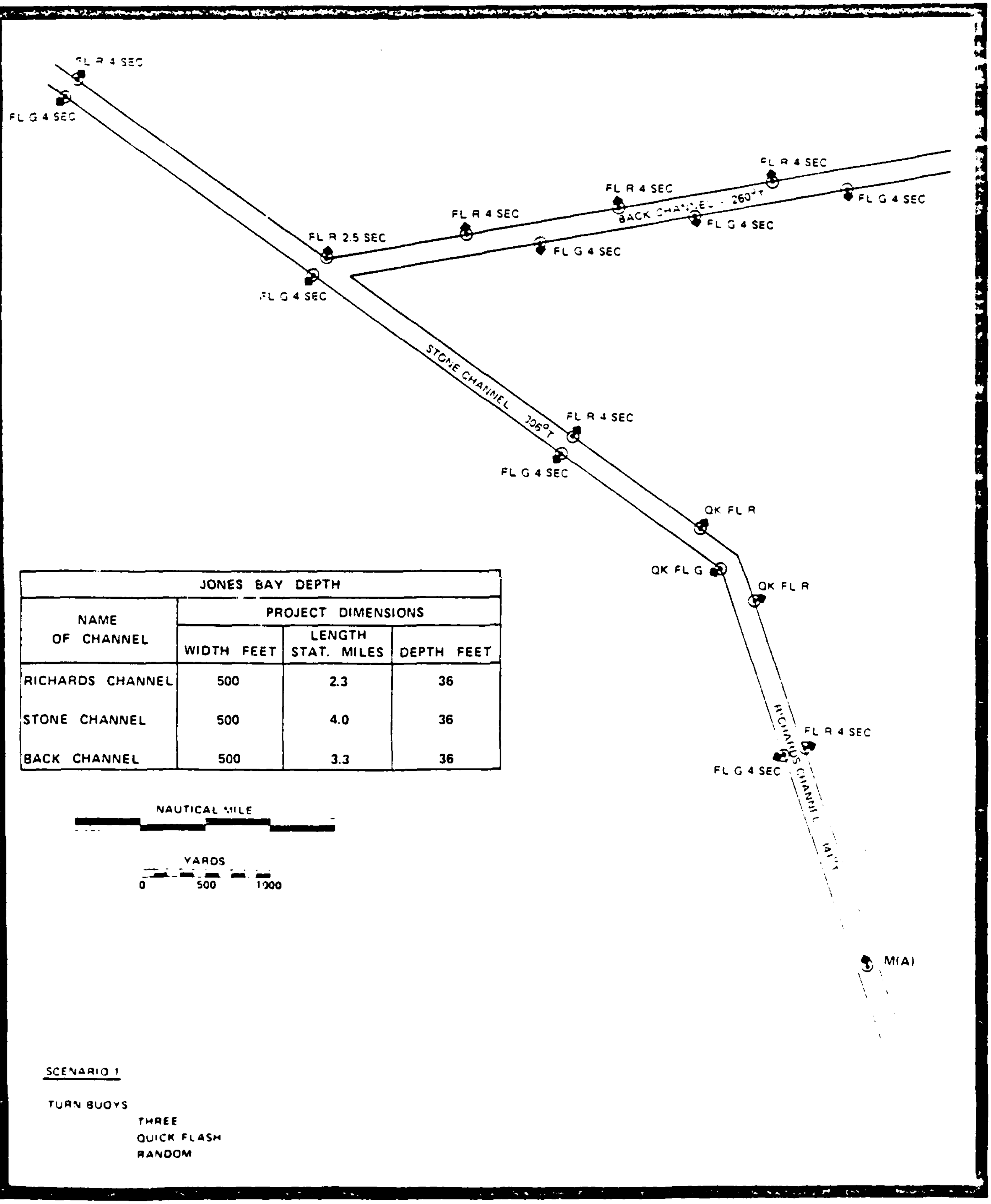
This treatment of the findings serves as an interpretation of the quantitative treatment. The same recommendations are supported above. For the 80,000 dwt ship only the maximum number of buoys will do and then only in the daytime. For the 30,000 dwt ship as few as one buoy will do in the daytime and possibly at night as well.

TABLE 7. PERFORMANCE IN NONCUTOFF TURNS

	Day			Night		
	Experiment	Scenario	Qualitative Evaluation	Experiment	Scenario	Qualitative Evaluation
30,000 dwt ship						
Three buoys	One Side	1	Optimal	Turn Light	1	Optimal
Two buoys	One Side	6	Acceptable	Turn Light	8,9	Acceptable
One buoy	Ship Variables	2	Acceptable			
80,000 dwt ship						
Three buoys	Ship Variables	7	Acceptable			
Two buoys				Turn Light	10	Unacceptable
One buoy	Ship Variables	6	Unacceptable			

APPENDIX A

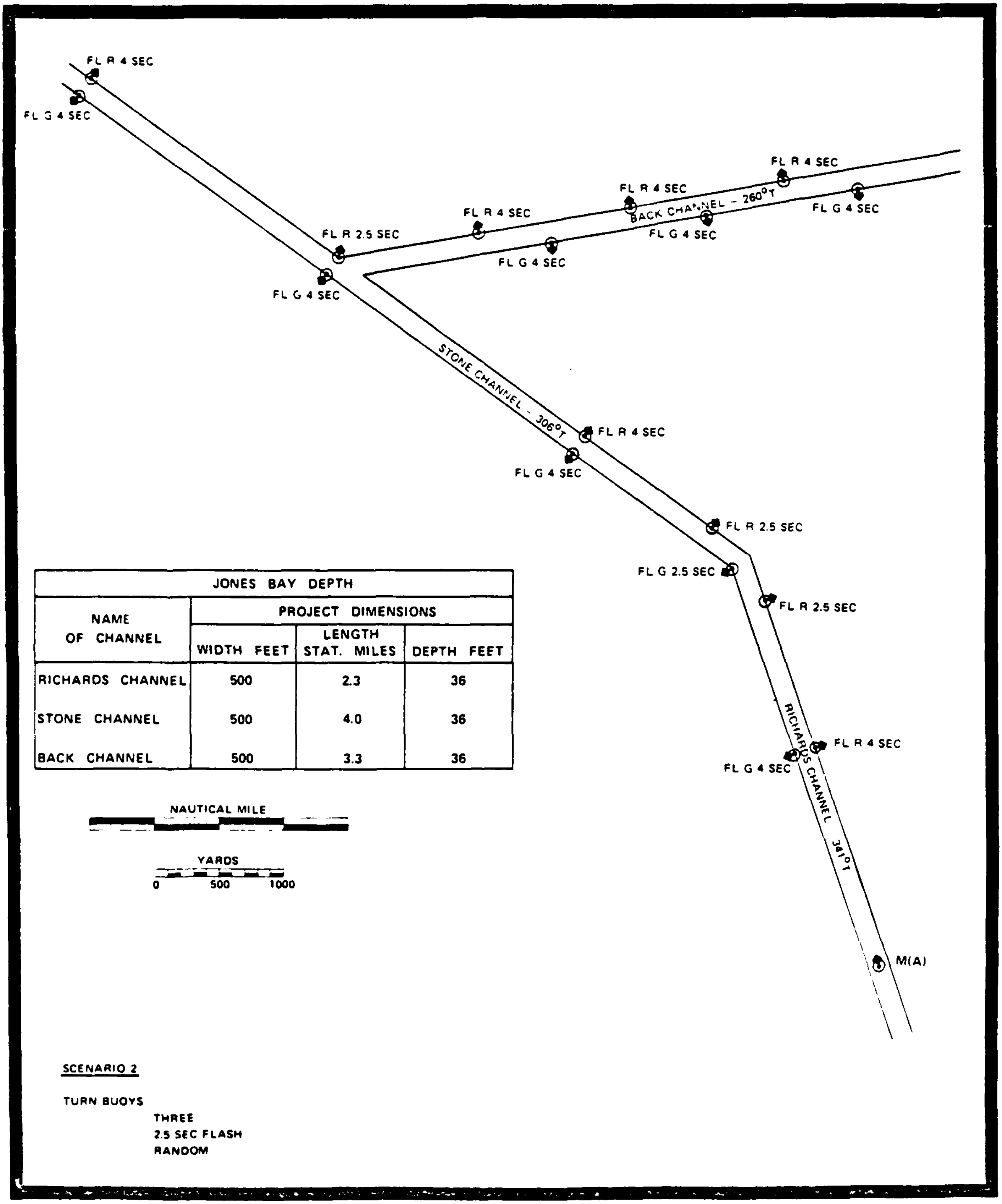
Scenario Diagrams



JONES BAY DEPTH			
NAME OF CHANNEL	PROJECT DIMENSIONS		
	WIDTH FEET	LENGTH STAT. MILES	DEPTH FEET
RICHARDS CHANNEL	500	2.3	36
STONE CHANNEL	500	4.0	36
BACK CHANNEL	500	3.3	36

SCENARIO 1

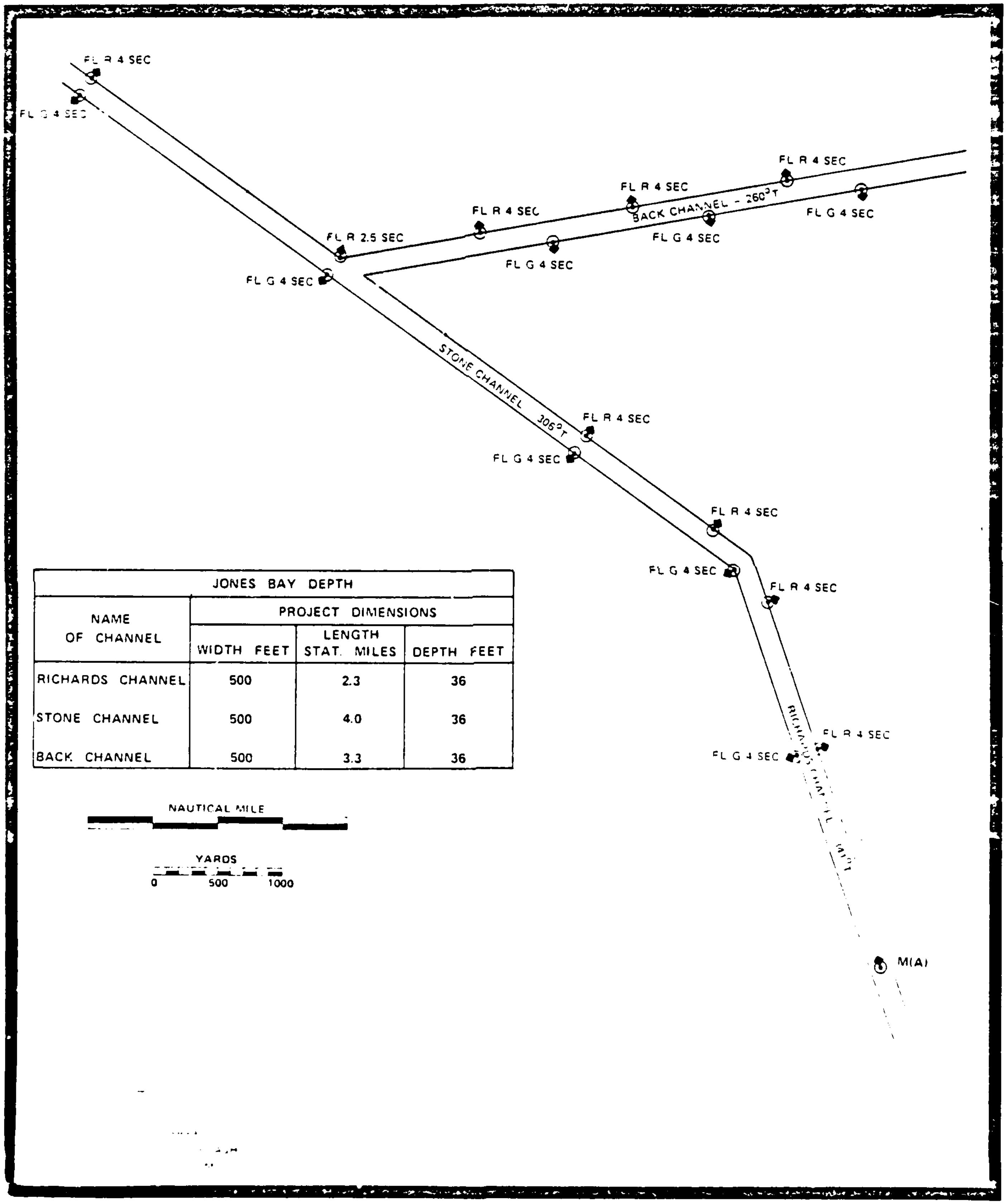
TURN BUOYS
THREE
QUICK FLASH
RANDOM



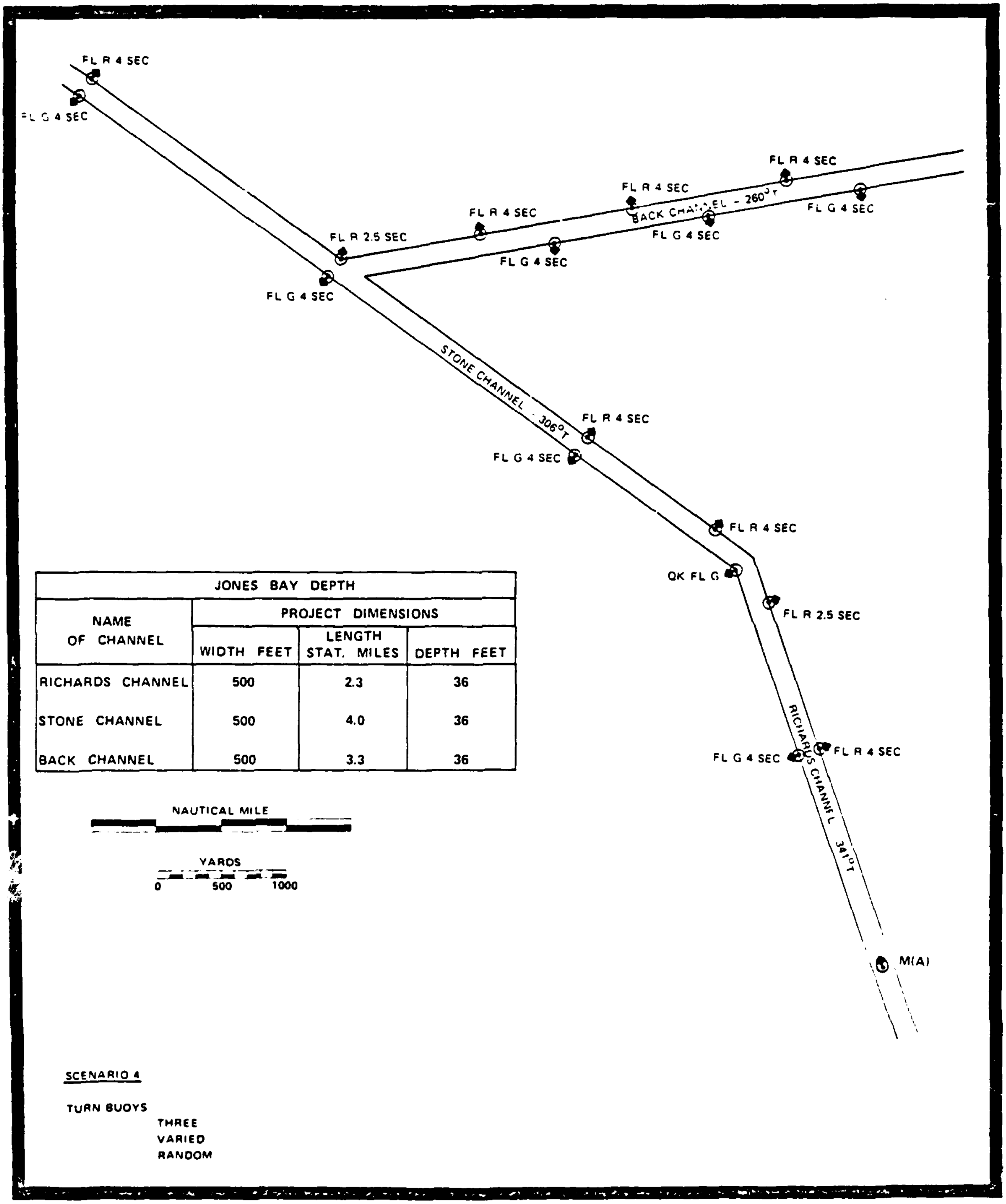
JONES BAY DEPTH			
NAME OF CHANNEL	PROJECT DIMENSIONS		
	WIDTH FEET	LENGTH STAT. MILES	DEPTH FEET
RICHARDS CHANNEL	500	2.3	36
STONE CHANNEL	500	4.0	36
BACK CHANNEL	500	3.3	36

SCENARIO 2

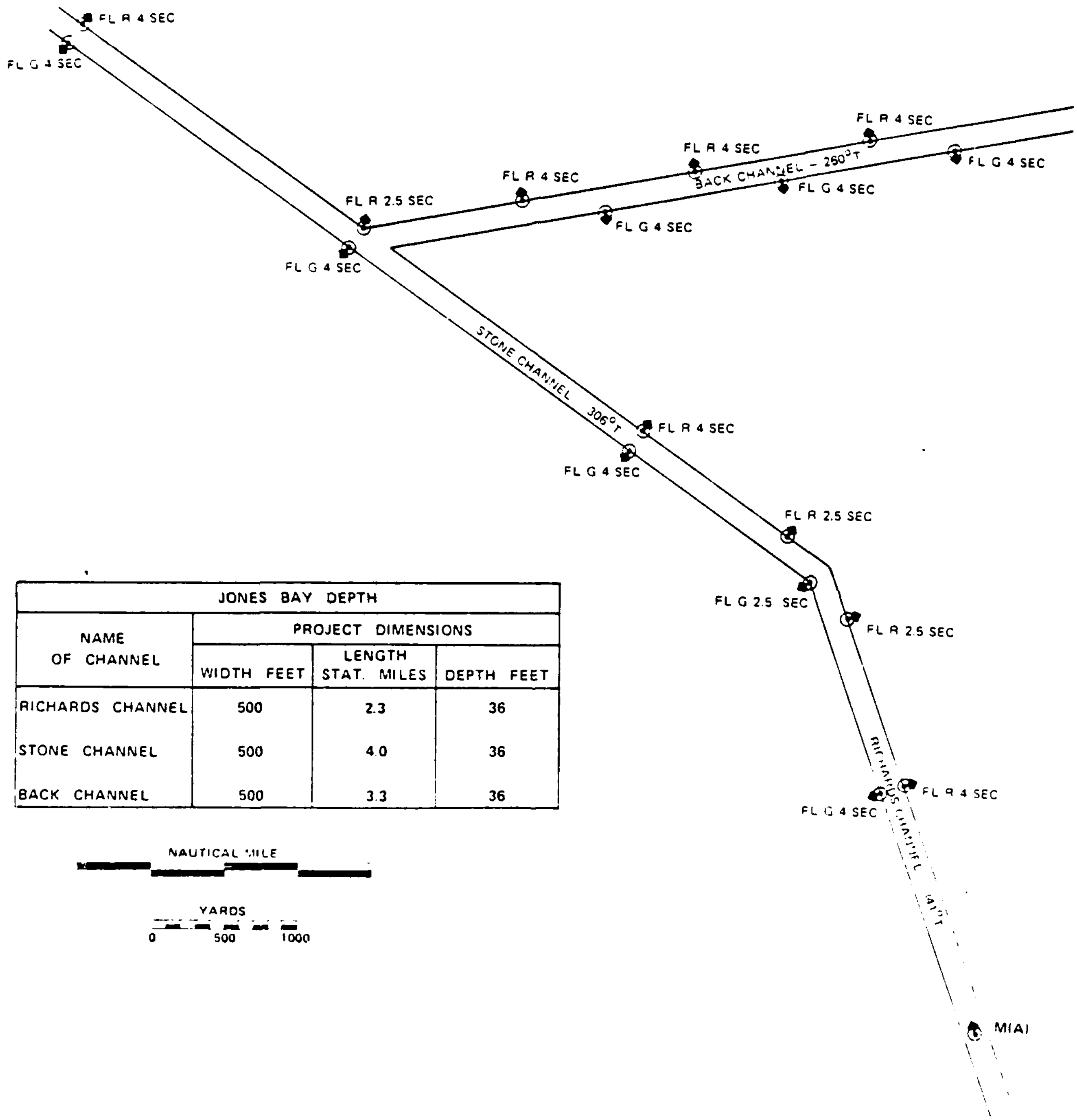
TURN BUOYS
THREE
2.5 SEC FLASH
RANDOM



JONES BAY DEPTH			
NAME OF CHANNEL	PROJECT DIMENSIONS		
	WIDTH FEET	LENGTH STAT. MILES	DEPTH FEET
RICHARDS CHANNEL	500	2.3	36
STONE CHANNEL	500	4.0	36
BACK CHANNEL	500	3.3	36



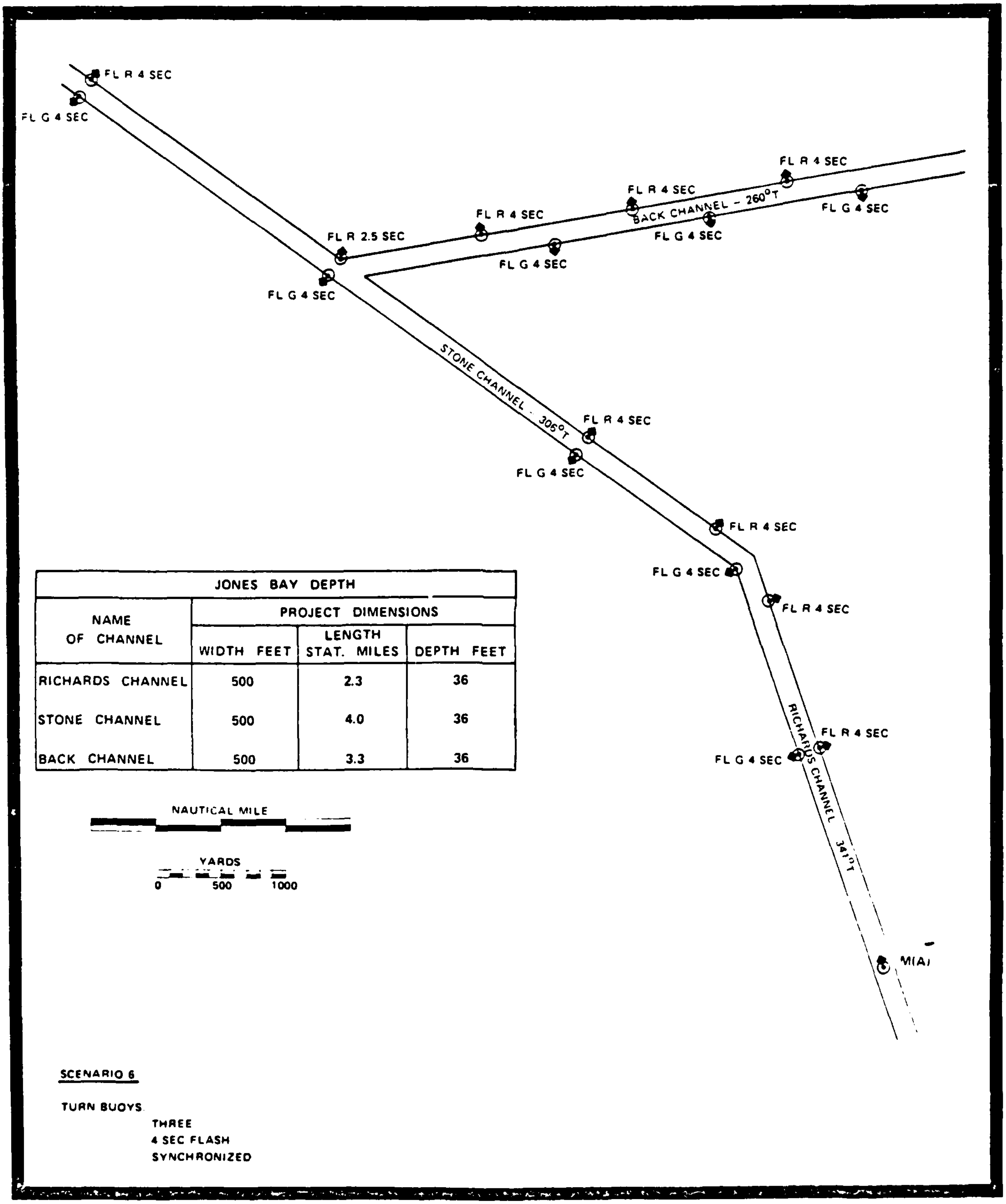
JONES BAY DEPTH			
NAME OF CHANNEL	PROJECT DIMENSIONS		
	WIDTH FEET	LENGTH STAT. MILES	DEPTH FEET
RICHARDS CHANNEL	500	2.3	36
STONE CHANNEL	500	4.0	36
BACK CHANNEL	500	3.3	36



JONES BAY DEPTH			
NAME OF CHANNEL	PROJECT DIMENSIONS		
	WIDTH FEET	LENGTH STAT. MILES	DEPTH FEET
RICHARDS CHANNEL	500	2.3	36
STONE CHANNEL	500	4.0	36
BACK CHANNEL	500	3.3	36

SCENARIO 5

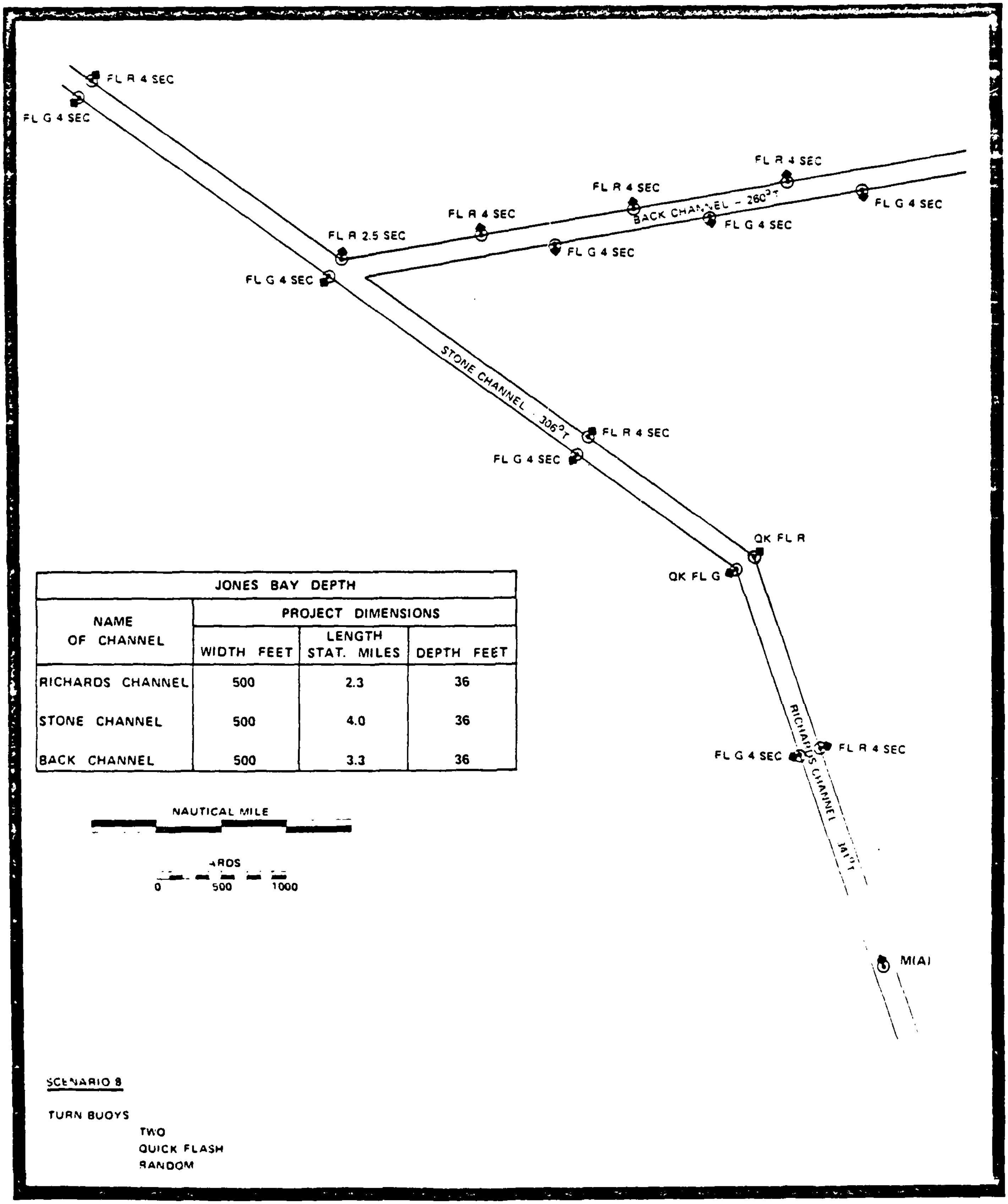
TURN BUOYS
THREE
2.5 SEC FLASH
SYNCHRONIZED



JONES BAY DEPTH			
NAME OF CHANNEL	PROJECT DIMENSIONS		
	WIDTH FEET	LENGTH STAT. MILES	DEPTH FEET
RICHARDS CHANNEL	500	2.3	36
STONE CHANNEL	500	4.0	36
BACK CHANNEL	500	3.3	36

SCENARIO 6

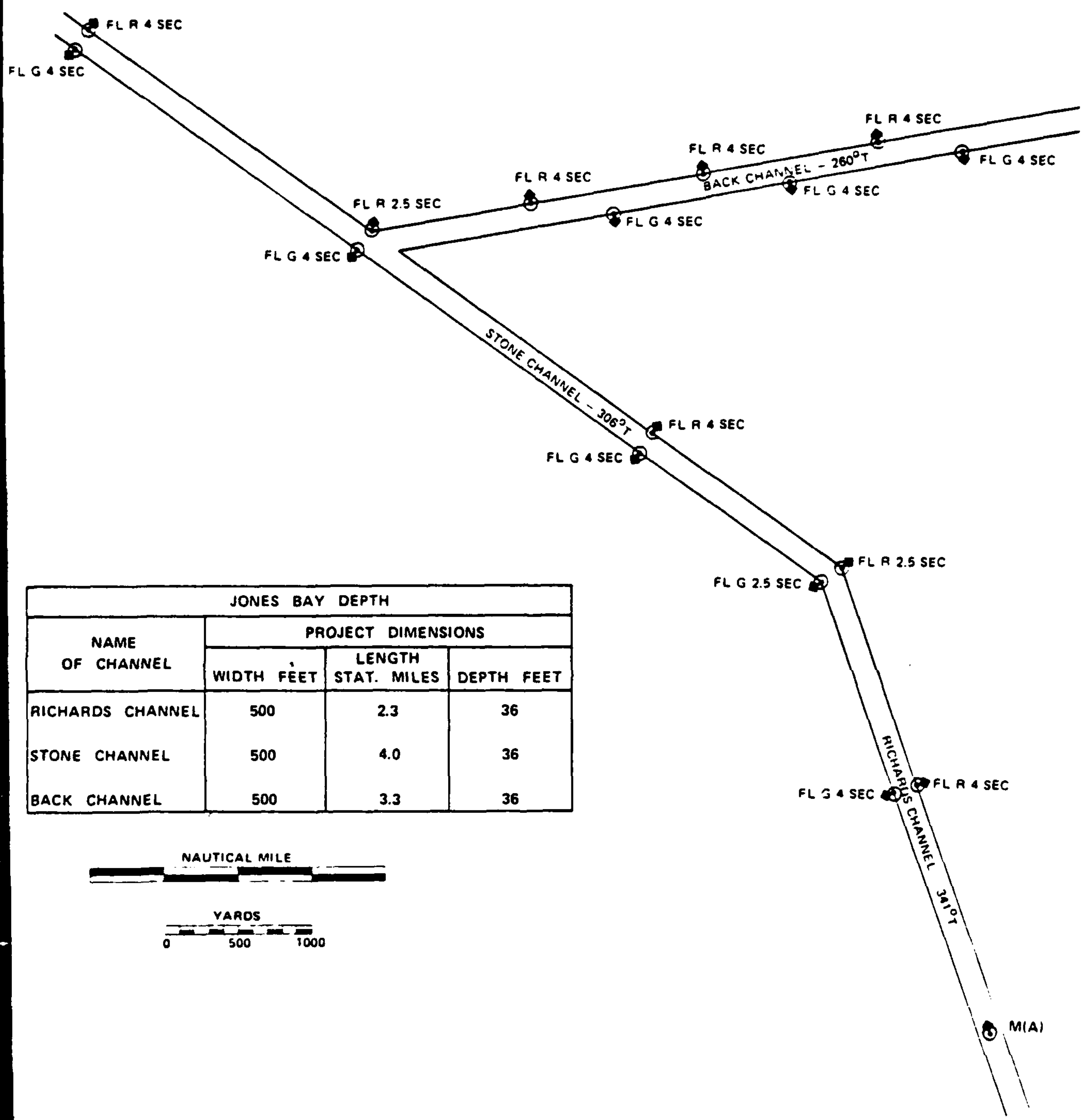
TURN BUOYS
THREE
4 SEC FLASH
SYNCHRONIZED



JONES BAY DEPTH			
NAME OF CHANNEL	PROJECT DIMENSIONS		
	WIDTH FEET	LENGTH STAT. MILES	DEPTH FEET
RICHARDS CHANNEL	500	2.3	36
STONE CHANNEL	500	4.0	36
BACK CHANNEL	500	3.3	36

SCENARIO 8

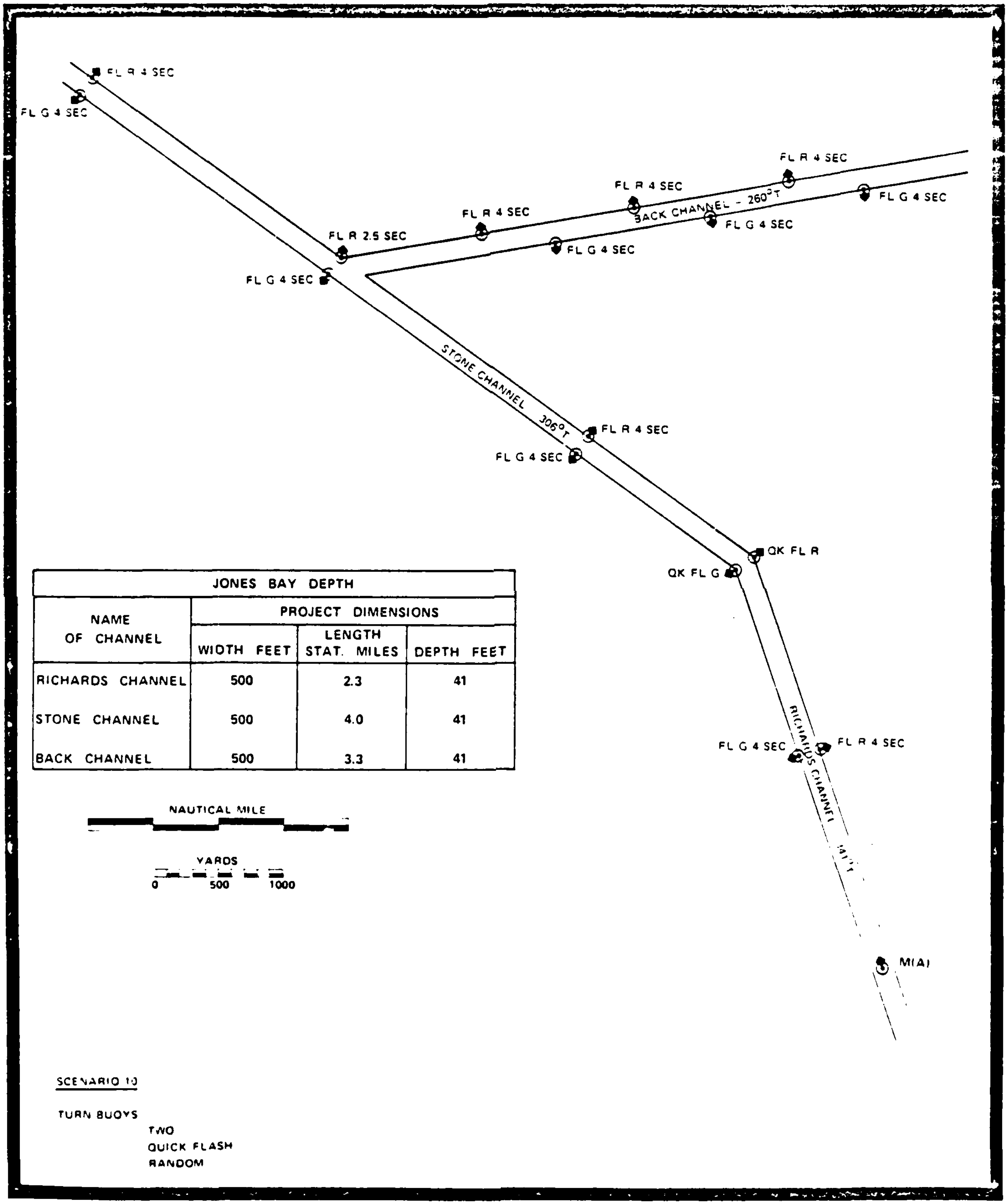
TURN BUOYS
TWO
QUICK FLASH
RANDOM



JONES BAY DEPTH			
NAME OF CHANNEL	PROJECT DIMENSIONS		
	WIDTH FEET	LENGTH STAT. MILES	DEPTH FEET
RICHARDS CHANNEL	500	2.3	36
STONE CHANNEL	500	4.0	36
BACK CHANNEL	500	3.3	36

SCENARIO 9

TURN BUOYS
TWO
2.5 SEC FLASH
SYNCHRONIZED



JONES BAY DEPTH			
NAME OF CHANNEL	PROJECT DIMENSIONS		
	WIDTH FEET	LENGTH STAT. MILES	DEPTH FEET
RICHARDS CHANNEL	500	2.3	41
STONE CHANNEL	500	4.0	41
BACK CHANNEL	500	3.3	41

SCENARIO 10

TURN BUOYS
TWO
QUICK FLASH
RANDOM

Appendix B

NIGHTTIME BUOYS AND PERCEPTUAL JUDGMENTS

Consideration of the problem presented to the pilot by nighttime conditions and flashing lights acts as a guide to the selection of variables and conditions that can be expected to affect performance. The characteristics of nighttime buoys and their hypothesized effects on the perceptual judgments made by pilots are summarized in Table B-1. The variety of perceptual judgments of which human beings are capable have been divided and labeled in a number of ways,[15,16,17] based primarily on laboratory tasks. The headings of the columns in Table B-1 describe a simple division appropriate for the purposes of this experiment into piloting performance. By "detection" is meant a judgment by the subject, the pilot, that he has experienced a stimulus, a light. "Recognition" is meant as a broad category in which the pilot may make several judgments: the light is a buoy; it is marking a particular segment or turn; it is marking one side or the other of the channel; and, ultimately, it is buoy "3A." (This final step of recognition is often called "identification." "Identification" seems to be the more familiar concept to the maritime industry; so that, rather than "recognition," is used in the main text of this report.) "Quantification" is also a broad category of judgments. Here, the pilot quantifies the information the buoy offers in whatever way is available to him: the buoy is close, far, 1 nm away, two ship lengths away; the buoy is fine on the bow, two points off the bow, opening, closing; the buoy forms a range, a gate, or outlines a turn in combination with other visible buoys. (The division of the judgments to be made into three groupings is not meant to imply that they are independent of each other.)

The first characteristic of nighttime buoys listed in Table B-1 is that they appear as point sources of light. This means that a variety of cues available in the daytime are missing: for example, the size and detail of the buoy, the texture of the water surface, etc. This lack affects the judgments to be made. The first, detection, is not affected. For this experiment, as for the earlier visual experiments in this project, detection is not a matter of uncertainty or judgment. The light appears on the simulator screen at the desired detection distance. Some of the cues for recognition are missing. To the extent that perceived detail and distance contribute to the recognition of a buoy as that one marking a particular point on the channel ahead, recognition is more difficult. Quantification

[15]R.R. Bush, E. Galanter, and R.D. Luce. "Characterization and Classification of Choice Experiments." In R.D. Luce, R.R. Bush, and E. Galanter (eds.). Handbook of Mathematical Psychology. (Volume 1). New York: Wiley, 1963.

[16]T. Engen. "Psychophysics I: Discrimination and Detection" and "Psychophysics II: Scaling Methods." in J.W. Kling and L.A. Riggs. Woodworth and Scholosberg's Experimental Psychology. Third Edition, New York: Holt, Rinehart and Winston, 1971.

[17]E. Galanter. "Contemporary Psychophysics." New Directions in Psychology. New York: Holt, Rinehart and Winston, 1962.

TABLE B-1. NIGHTTIME BUOYS AND PERCEPTUAL JUDGMENTS

	Detection	Recognition (Identification)	Quantification
Point source: poor distance cues	Given	Hurts recognition slightly	No distance - off, must use relationship
Flashing: absolute and differential rates	Slower rate, more attention needed	Differential rates help recognition	Slower rate, more processing needed
Random in relation to other buoys	Detection, recognition of pattern requires time, attention, memory		One at a time or memory

is affected as well. The only reliable cue to directly estimating the distance to a buoy (what pilots call the "distance-off" method) is the height of the light in the visual field. Because of the paucity of cues for direct judgments, the pilot must depend on such cues as the light's relationship to visible parts of the ship or to other lights.

That the buoy light is not constant but flashing has implications for the pilot's perceptual judgments as summarized by the second line in Table B-1. Extra attention is required to detect each flash: probably, the slower the flash, the more attention is required. Recognition is potentially helped by the nature of the flash. Quick flash (0.3 second on, 0.7 second off) is distinctive and easily recognized against a variety of background lights. Other flash rates might be helpful when they are different from the competing possibilities. Quantification is made more difficult by the flashing of the light; to estimate distance or to judge the relationship of the buoy to the ship or to other buoys takes more time or attention or processing than would be the case for a steady light. The slower the flash, the more processing is required. In other words, the pilot must wait for the light to reappear.

The usual random temporal relationship of flashing buoy lights in physical proximity to each other has consequences for the pilot's judgments. In addition to the information provided by an individual buoy, buoys in close proximity potentially present a pattern as well: for example, a gate, a range, a turn outline, a straightaway outline, etc. At night, the detection and recognition of this pattern takes time and attention as the pilot waits for each member of the pattern to appear. For the quantification of information, the pilot has a choice of using the lights one at a time as they appear and not benefiting from the pattern; or filling in the missing lights from memory which takes time and effort, and potentially results in a distortion of his judgments.[18] Notice that the point source nature of the light forces the pilot to depend on patterns or relationships to quantify

[18] J. Smith and H. Kaufman. "Identification, Discrimination, and Match-to-Sample as Instances of Comparative Judgment." Perception and Psychophysics, 1977, Vol. 21 (3), 253-258.

the information presented to him, but the random flash makes such dependence difficult.

It should be pointed out that the perceptual judgments that are the focus of the present experiment are only a part of the complex process of piloting as it is measured by simulation in this project. After making these perceptual judgments, the pilot must evaluate the position, velocity, and acceleration of the ship and decide whether to order a change in helm or engine. After this, the performance of the helmsman and the responsiveness, or inherent controllability, of the ship contribute to the performance measures of interest -- the position of the ship's center of gravity as it transits the channel. It is quite possible that realistic manipulations of these perceptual judgments will not result in measurable differences in ship tracks.

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